2016-1299, -1300

United States Court of Appeals for the Federal Circuit

LEAK SURVEYS, INC.,

Appellant,

v.

FLIR SYSTEMS, INC,

Appellee.

Appeals from the United States Patent and Trademark Office,
Patent Trial and Appeal Board in
Case Nos. IPR2014-00411, IPR2014-00434, and IPR2015-00065

OPENING BRIEF OF APPELLANT LEAK SURVEYS, INC.

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CERTIFICATE OF INTEREST

Counsel for the Appellant, Leak Surveys, Inc., certifies the following:

The full name of every party or amicus represented by me is:

Leak Surveys, Inc.

The name of the real party in interest (if the party named in the caption is not the real party in interest) represented by me is:

Not applicable.

All parent corporations and any publicly held companies that own 10 percent or more of the stock of the party or amicus curiae represented by me are:

None.

The names of all law firms and the partners or associates that appeared for the party or amicus now represented by me in the trial court or agency or are expected to appear in this Court are:

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TABLE OF CONTENTS

TABLE OF AUTHORITIES

Page(s)

Cases

Statutes

Regulations

STATEMENT OF RELATED CASES

In accordance with Federal Circuit Rule 47.5(a) and (b), Appellant states:

1. Appellant is unaware of any other appeal in or from the same proceeding below that was previously before this or any other appellate court.

2. Appellant filed an action for patent infringement on July 25, 2013, alleging infringement of U.S. Patent No. 8,193,496 and U.S. Patent No. 8,426,813. The case is active, but is stayed pending the outcome of this appeal: *Leak Surveys, Inc. v. FLIR Systems, Inc.*, Case No. 3-13-cv-02897 in the United States District Court for the Northern District of Texas.

I. STATEMENT OF JURISDICTION

On September 3, 2015, the Patent Trial and Appeal Board ("Board" or "PTAB") issued the Final Written Decision ("FWD") below. Pursuant to 35 U.S.C. §318(a) and 37 C.F.R. §42.73, the Board's FWD adjudicated three *inter partes* review proceedings that had been filed by Appellee FLIR, Inc. ("FLIR"). Appellant and Patent Owner Leak Surveys, Inc. ("LSI") timely filed a Notice of Appeal on October 30, 2015, pursuant to 35 U.S.C. §142 and 37 C.F.R. §90.3. (A1804-09; A28815-20) This Court has appellate jurisdiction pursuant to 28 U.S.C. §1295(a) and 35 U.S.C. §§141(c) and 319.

II. STATEMENT OF THE ISSUES

The following issues are presented on appeal:

1. Whether the Board's claim construction of "leak" was erroneous;
2. Whether the Board's claim construction of claim terms requiring "variable ambient conditions" and/or "normal operating conditions" was erroneous;
3. Whether the Board erred in finding that the alleged combination of prior art references would detect a "leak" under "variable ambient conditions" and/or "normal operating conditions";
4. Whether the Board erred in finding that a POSITA would have been motivated to combine the references as alleged by FLIR;
5. Whether the Board erred in finding no nexus between the challenged claims and the objective evidence of non-obviousness, and in refusing to give weight to the objective evidence in connection with its obviousness determinations;
6. Whether the Board's obviousness determinations were legally erroneous and/or whether its factual findings were supported by substantial evidence; and

7. If the Court finds error in the decision below, whether the case should be remanded, or whether judgment should be rendered for LSI.

III. STATEMENT OF THE CASE

Appellant LSI appeals from three *inter partes* review ("IPR") proceedings involving two related patents: U.S. Patent No. 8,193,496 (the "'496 Patent") (A52-101) and U.S. Patent No. 8,426,813 (the "'813 Patent") (A102-51). Both patents claim priority to common provisional and PCT applications.[1] The '813 Patent is a continuation of the '496 Patent. (A102)

Appellee FLIR Systems, Inc. ("FLIR") filed five IPR petitions challenging these patents. In a consolidated Decision to Institute, the Board granted the petitions in the -411 and -434 IPRs and denied the remaining two petitions. (A354-90) The Board then consolidated the -411 and -434 cases. (A391-95) FLIR subsequently filed a fifth petition, which the Board later granted. (A27796-815) Following institution of the -065 case, the Board coordinated the deadlines, including discovery, between the -411 and -065 cases, and the parties thereafter filed consolidated briefing; but the cases were never consolidated.[2]

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[1] When citing to the patent specification, LSI cites to the '496 Patent only; but all such citations are equally applicable to the corresponding portions of the '813 Patent.

[2] With only a few exceptions, all evidentiary exhibits are common to the -411 and -065 cases. In this brief, LSI will primarily cite only the -411 evidence, but these citations are equally applicable to the -065 appeal unless otherwise noted.

The Board entered a consolidated Final Written Decision ("FWD") on September 3, 2015. (A1-51) LSI timely filed its Notices of Appeal. (A1804-09; A28815-20)

IV. STATEMENT OF FACTS

The IPR proceedings below resulted in the creation of a dense factual record involving 24 declarations and 14 depositions. (A24800-01) Almost all witnesses were scientists (many with Ph.D. degrees) having ***personal knowledge*** of the petroleum industry's extensive efforts (and failures) to develop a commercially viable imaging system for detecting hydrocarbon gas leaks in the field. Most of these same witnesses also offered first-hand testimony of David Furry's own efforts to solve the same technical problem. Several witnesses –top scientists from the largest petroleum companies – described the day in 2004 when Furry showed up at the industry's "Scan Off" to demonstrate his "Hawk" camera against the industry's then-best optical leak detection systems.[3] These scientists, having dedicated years of work and countless resources to creating a commercially viable optical leak detection system, testified that they were completely surprised and astonished by the Hawk's unexpected results. It was immediately apparent that Furry had solved an important technical problem that the petroleum industry had been unable to solve. (A17620-23; A17627-29; A16126-31; A15526-31)

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[3] The American Petroleum Institute's extensive efforts, culminating in the "Scan Off," were documented in the "Environ Report." (A13387-619; A17614-22) The Environ Report is a critical document in this case for many reasons discussed throughout this brief. *See, e.g.*, A13542-49 (API's literature survey).

David Furry, his company LSI, and his Hawk camera are famous in the petrochemical Leak Detection and Repair ("LDAR") community for having revolutionized LDAR. (A17565-66; A13871-75) Furry was the first to build and demonstrate a passive infrared ("passive-IR") imaging device that could visually detect gas leaks with 100% accuracy for leaks above the camera's detection threshold. (A17622-23) His camera also boasted the lowest detection threshold compared to other systems. (A17620-21) Today, practically every petrochemical facility in America uses a passive-IR camera[4] – with specifications essentially identical to the Hawk – as the technology of choice for LDAR. (A16134 ¶¶78-79; A17631-32; A23928-29; A23942; A23944) The Furry-designed passive-IR camera has become an alternative work practice for Method 21. (A17630-31)

The remarkable factual record below consists of testimony from the following key witnesses:

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[4] "Passive-IR" refers to infrared systems that rely upon naturally occurring IR radiation, as opposed to "active-IR" systems that supply an independent source of IR radiation, such as with a laser. (A20243-45 ¶¶123-127) The claims at issue are limited to passive-IR systems, and only passive-IR prior art is at issue in this proceeding.

- Dr. Jeff Siegell and Wayne Sadik, former ExxonMobil employees. Seigell headed the API's LDAR group, and Sadik assisted. (A13389; A16108-10; A16135-39; A17007-08)
- Dr. Douglas Hausler (former Philips Petroleum) and Dave Fashimpaur (BP). Each played an active part in the API's LDAR initiative (A13389; A15496; A15537-43; A17612-14; A17635-40)
- Mike Smylie, an environmental consultant from Environ who was hired to design, implement, and document the API's "Scan Off" near Houston, Texas. (A13389; A17079-81; A17091-95)
- Barry Feldman, a former EPA employee charged with directing Smart LDAR research (A13389; A17055-56; A17066-69)
- Jeff Leake, an infrared camera dealer who has personal knowledge of David Furry's conception and reduction to practice activities, having assisted David in ordering the Hawk prototypes from Indigo. (A16675-80; A16683-95)
- Dr. William (Bill) Parrish, a well-known pioneer in infrared technologies. He was the founder of Amber Engineering (acquired by

Raytheon) and a co-founder of Indigo (acquired by FLIR[5]), both of which developed infrared technologies for aerospace, commercial and military applications. Parrish personally oversaw the development and marketing of the Merlin-MID camera – the primary reference used by FLIR for each asserted ground of unpatentability, and the camera modified by David Furry. (A6979-80; A17521-22; A17534-37)

- Dr. William Hossack, a co-author of the Strachan reference at issue in this case. (A2858; A15014-16; A15040-50)
- Dr. James T. Wimmers, author of a critical prior art reference considered during prosecution, who submitted a declaration to the examiner during prosecution. (A24305-09)
- Dr. Austin Richards, a long-time FLIR/Indigo employee who joined Indigo after the Merlin-MID was developed and worked under Bill Parrish. Dr. Richards currently is a senior scientist for FLIR. (A7936; A21588; A21591-92)

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[5] FLIR purchased Indigo in early 2004. Throughout this brief, references to activities of FLIR are also intended to include the activities of Indigo prior to FLIR's acquisition.

- James Woolaway, a co-founder of Indigo (along with Bill Parrish) who stayed with the company when it was acquired by FLIR, and served for many years as FLIR's Chief Intellectual Property Officer prior to his retirement in 2010. Like Parrish, he was a lead designer of the Merlin-MID camera. (A8958-60)

Each side also offered expert testimony. Leak Surveys' expert is Dr. Rainer Martini, who holds a Ph.D. and is a professor of physics at Stevens Institute of Technology. (A20191-96; A20354-55; A20471-74) FLIR offered the expert testimony of Dr. Jonas Sandsten, who also holds a Ph.D. in physics. (A2787-88; A2847-51) Dr. Sandsten is a FLIR consultant who became a full-time FLIR employee just one month prior to the date of his first IPR declaration. (A18210-12)[6]

A. Leak Detection and Repair ("LDAR") and the Petroleum Industry's Extensive Efforts to Develop a Commercially Viable Gas Imaging System for Field Use.

In the petrochemical industry, "Leak Detection and Repair" or "LDAR" is the technical endeavor of locating and repairing hydrocarbon gas leaks. (A13376; A13409-10; A16114) In the 1980s, the EPA mandated "Method 21" as the

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[6] All of FLIR's substantive testimony in this case was offered by five current full-time FLIR employees, several who were former Indigo employees, and FLIR's recently retired chief IP officer.

required technology for LDAR. (A13320; A16115-17) Method 21 relied upon hand-held "sniffers" that a technician would place near places known to be a likely gas leak source. Method 21 was cumbersome, costly, very inefficient, and prone to false readings. (A86 1:42-58; A17615-17 ¶¶10-13; A17057-59 ¶¶12-18; A16115-17)

Beginning in the early 1990s, the petrochemical industry aggressively searched for an acceptable replacement to Method 21, led by a group of researchers coordinating through the API, the US Environmental Protection Agency ("EPA"), and state environmental agencies. (A13409-11; A17617; A16119-22) They coined the term "Smart LDAR" to refer to the as-yet unknown solution. (A16117 ¶29)

In 1999, the EPA commissioned a study to investigate potential technology platforms for Smart LDAR as a potential alternative work practice to Method 21. (A13409-11) The EPA and API were willing to consider any potential technology. (A13411-13)

The LDAR technical problem being addressed by the petroleum industry at that time was the ***exact same technical problem*** addressed by the Furry patents at issue.[7] A comparison of the "Background" section of the patents with the industry's Environ Report conclusively demonstrates this. *Compare* A86 1:30-2:33 with A13395-96 and A13409-25. *See also* A16117-22; A17617-18.

Of ***critical importance*** to this appeal, the technical problem being addressed ***was not*** the problem of simply imaging a gas. Instead, the industry was evaluating existing gas imaging technologies to determine whether they could detect unknown "leaks" in a petrochemical plant – leaks which, by nature, were not known in size or location and which existed in unpredictable and uncontrolled environmental conditions. (*See id.* – previous string cite)

It is undisputed that several known prior art systems were capable of imaging a gas under ***some*** conditions - in particular, when there is a sufficient "Delta-T," *i.e.*, a difference in temperature between the background and the gas, and more so if the filter bandwidth was broad. (A20249-55 ¶¶136-146; A20259-60 ¶¶157-158; A22488-89; A86 1:59-2:25; A17524-25 ¶¶12) Thus, the technical problem being addressed by the industry and Furry was whether these known prior

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[7] At this time, Furry was the operations manager for Brady, Texas, which owned a 42-mile hydrocarbon transmission line and several miles of gathering lines. His job responsibilities included the detection of fugitive leaks from these petrochemical facilities. (A13372-73)

art imaging systems could be ***suitable or adapted for field use*** under normal operating conditions at petrochemical facilities, where the ambient conditions (such as temperature or wind) are not controlled, and are variable within an expected range, and/or where the leak location is unknown. (*See* A13423 ("One of the basic questions evaluated in this study is whether gas-imaging devices can be used to effectively detect fugitive emissions ***under conditions typically found in refineries and chemical plants***."); A16125-16129 ¶¶50,52,64; A17624 ¶30; A86 2:23-25 ("Hence, a need exists for a way to perform a visual inspection to find leaks with reliability and accuracy, while being faster and more cost effective than existing leak survey methods."))

B. Prior Art Gas Imaging Systems were not Suited for LDAR under Real-World Field Conditions.

Prior to 2004, many prior art systems were known to be capable of imaging gases under certain narrow conditions. But none of them were capable of reliably detecting fugitive gas leaks under real-world conditions. (A13410-25; A13542-49; A22489-90; A86 2:23-25) The prior art systems all shared a critical limitation – they only worked under a limited range of operating conditions, particularly where there was a sufficient temperature differential or "Delta –T," a condition that is rarely present under normal operating conditions in the field. (*Id.*)

This is true, for example, of FLIR's own Merlin-MID camera. As will be discussed below, the Merlin-MID is capable of imaging gases only when there is a relatively-high temperature contrast between the gas and its background. (A17524-26 ¶¶12,16; A7938 ¶6; A20294-98 ¶¶233-243) FLIR has never marketed its Merlin-MID camera for LDAR, and does not contend in this case that it would be suitable for detecting gas leaks in the field, under real-world variable conditions. (A17524-25 ¶¶12,16; A21752-53 197:23-198:23, 201:7-203:18; A23928-29; A23933)

Similarly, the Strachan and Kulp references (that FLIR offers in combination with the Merlin-MID publications) each disclose that their respective passive-IR systems can only image gases under a narrow range of ambient conditions – particularly, where there is a sufficient Delta-T. *See* Sections IV(E)(2) and IV(E)(3), below.

FLIR's expert for this case, Dr. Jonas Sandsten, was attempting to solve the same technical problem during this time frame. His proposed "gas correlation technique" required use of uncooled filters, a second optical path, and additional equipment to image gas, including a heater to illuminate the background, or uniform backgrounds. Dr. Sandsten's system did not work under uncontrolled field conditions, and it was not adopted by the API or EPA. (A20320-23; A3330-32; A22490; A13412; A13548)[8]

During prosecution, the examiner (and also the BPAI) considered other optical imaging art, most or all of which was referenced in the Environ report and well known to researchers at the time. All references suffered from the same deficiency – an inability to translate successful imaging under limited or controlled conditions into a system capable of working under real-world, variable conditions. (A13378-85)

C. Furry's Novel Passive-Infrared Gas Imaging System Solved a Technical Problem that the Petrochemical Industry Could not Solve.

1. Technical Background - Passive-IR Imaging.

Furry's patented leak-detection system relies upon passive-IR imaging. (A86 2:37-51)

Infrared imaging is founded upon the basic principal that all objects above absolute zero temperature both ***emit and absorb*** electromagnetic radiation. (A20220-21 ¶¶85-86) The intensity and wavelength of IR emissions from any

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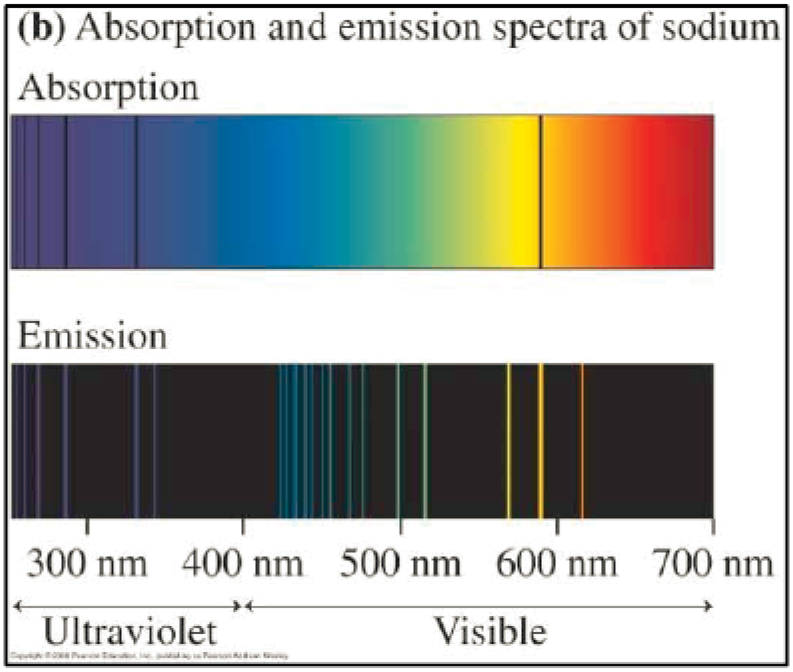
[8] It bears pointing out the irony that FLIR relys upon "expert" testimony from a scientist who failed to solve the same technical problem that Furry successfully solved. While Dr. Sandsten opined that Furry's technical solution was obvious at the time to a POSITA, one wonders why Dr. Sandsten himself (along with everyone else) failed to conceive of it.

object correlates closely to its temperature, following Planck's law. A theoretically ideal Planck blackbody held at an exact known temperature emits radiation at a variety of wavelengths, with the peak of the emission curve correlating to temperature. (A20227-30 ¶¶100-104) Actual objects in the real world similarly emit IR radiation at a variety of wavelengths, with hotter molecules emitting more IR radiation (and at higher peak wavelengths) than the same molecules at a cooler temperature. (*Id.*)

All molecules also absorb IR radiation. (A20201-02 ¶43) The wavelengths absorbed by any particular molecule (i.e. its "absorption spectrum") are unique to that molecule (determined by its unique chemical makeup), and serve as a sort of fingerprint for the molecule. (A20231 ¶106) To illustrate, the figure below shows the emission and absorption spectra for sodium, with the absorption wavelengths depicted as holes within the entire spectral range and the emission wavelengths depicted as positive lines for an analogous visible light illustration.



(A20230-31 ¶105)

Using these principles, infrared technologies can be divided into “emission spectroscopy” and “absorption spectroscopy” instruments. (A20232-35 ¶¶107-110)

Emission Spectroscopy. Infrared imaging devices that rely upon emission spectroscopy are referred to as “thermal imaging devices.” (A17524, A17528 ¶11,21-22) These devices measure the temperature of objects in the field of view (and distinguish between objects at different temperatures within the field of view) by measuring the emission of IR radiation across a relatively broad band of wavelengths in order to identify the relative temperatures of the objects. (*Id.*; A20249-53 ¶¶136-146) To maximize the performance of a thermal imager’s ability to perform emission spectroscopy, the more IR information that is collected by the detector (i.e. higher ***sensitivity***), the more accurate the reading. (*Id*.; A21803-05 248:12-250:20) While IR thermal imagers typically use a bandpass filter to eliminate atmospheric absorption band noise, the filter's passband is relatively wide to maximize the amount of detected IR radiation. (A20241-43 ¶¶119-122; A6990-91 33:3-34:17) For example, FLIR's Merlin-MID camera (like most thermal imagers) uses a bandpass filter that permits all IR wavelengths between 3-5 microns on the electromagnetic spectrum to pass through to the detector (i.e. a 2 micron or 2000nm passband). (*Id*.; A21803-05 248:12-250:20) This is considered a "wide" passband filter, whereas filters with passbands in the range of 100 – 200nm are referred to as "narrow" filters. (A21700-05 145:19-150:11; A21952)

The 3-5 micron window was selected for thermal imaging because there is little interference (due to absorption) from the Earth's natural atmosphere within this window of the electromagnetic spectrum. (A21803-05 248:12-250:20; A20241-43 ¶¶119-122; A6990-91 33:3-34:17) For emission spectroscopy, ***avoiding*** absorption of IR radiation is a critical aspect of the design in order to maximize the instrument's sensitivity. (*Id*.)

Absorption Spectroscopy. Rather than avoiding absorption of IR radiation, absorption spectroscopy measures absorption as its principle of operation. Absorption spectroscopy identifies the absence of expected IR radiation at very particular wavelengths due to the absorption of IR radiation by a molecule of interest as compared to the background. Unlike emission spectroscopy, absorption spectroscopy requires a separate source of background radiation (i.e., other than the target itself) so that the target's absorption of the background radiation can be measured. (A20232-35) Unlike emission spectroscopy, absorption spectroscopy requires relatively narrow bandpass filters to eliminate IR wavelengths outside of the narrow absorption bands of interest; thus, making the instrument ***highly selective*** to a particular wavelength of interest. (A20221-24 ¶¶87-93, A20233-35, ¶¶107(d)-109; A17526 ¶16) Failure to sufficiently filter out IR wavelengths outside of the narrow bands of interest will result in the "wash out problem," where unabsorbed IR radiation will interfere with the detection of IR radiation absorption for the specific wavelengths of interest, and thus prevent successful imaging. (A7004-05 47:21-48:20; A15019-20 ¶¶25-27; A24307; A17524-25 ¶12; A20242 ¶122)

Absorption spectroscopy is more difficult when the background source temperature is variable. (A20259) Absorption spectroscopy relies upon a thermal contrast between the molecule of interest and the background (the "Delta-T"). The smaller the Delta-T, the more difficult gas is to detect. (A7001-4 44:15-47:8; A20258-60 ¶¶156-158) Under real-world conditions and where gas concentrations are low, however, the Delta-T will often be very small. (A20296 ¶239) For this reason, research to improve absorption-based IR instruments for field applications such as LDAR have long focused on successful detection of molecules under conditions with a minimal Delta-T and/or where Delta-T cannot be controlled. (A13542-49)

2. The Hawk Camera – Furry's Novel LDAR Solution.

Furry's Hawk prototype (the disclosed preferred embodiment in the patent specification) was a modified and custom-built Merlin-MID camera, with a novel filter configuration. (A88-89 5:34-6:64, 7:59-8:29) The Hawk embodied at least two critical design decisions: (1) the filter specification, which consisted of a fixed single filter configuration having a carefully selected width (i.e. aggregate passband) and center wavelength,[9] and (2) placement of the single filter configuration inside the refrigerated portion of the camera, in the same portion as the infrared detector. (*Id*.; A20204-07 ¶¶46-52)

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[9] The transmission curve showing the passband and center wavelengths for the filter used for the original Hawk prototypes can be seen at A22300-01. The Spectrogon transmission curve reports the passband in "wavenumbers," which is a scale for expressing the spatial frequency of a wave that can be converted to nanometers. *See also* A60 (Figure 5).

The first design decision – filter configuration – was a product of Furry's desire to detect multiple gases of interest (i.e., typical light hydrocarbons that leak in a chemical plant) with a single camera using a single filter configuration. (A89 8:30-52) Furry realized that the major hydrocarbons of interest for LDAR (such as methane, ethane, propane, butane and hexane) each have respective absorption spectra that tend to overlap at specific and fairly narrow bandwidths. (A89-90 8:30-9:12 and A60-62 Figures 5, 6 and 7 (overlaying the respective absorption bands of multiple gases of interest to show overlap))

Because of this physical property (the overlapping absorption bands for hydrocarbons of interest), Furry realized that a single narrow filter could be used to detect IR absorption by the potential presence of multiple gases of interest. *Id.* (showing that the passband of the filter depicted by transmission curve **80**, overlaps with the absorption band for multiple gases of interest)) The ability of an LDAR camera to detect multiple gases of interest with a single filter configuration is a significant advantage to operators by making the device more portable, allowing operators to do leak detection with one sweep of the field of view, and finding leaks of multiple chemicals of interest (e.g., methane or ethane) with a single camera. (A13921-24 ¶¶128-143)

Furry's selection of a narrow filter – ***but not too narrow*** – ran contrary to the teachings of the prior art. It was known in the art that narrow filters (under certain conditions) allowed absorption spectroscopy to detect the presence of one particular molecule at a time. For example, the Wimmers reference[10] taught the benefits of "extremely narrow-wavelength-band filters" and stated that filters as narrow as 0.04 micron (40 nanometers) had been demonstrated effective in detecting ***single*** molecules of interest. (A24160-61). But the art also taught that the ideal filter was the narrowest possible filter, focusing very narrowly on the smallest possible sliver of the IR spectrum, in order to avoid the "wash out problem" that can be caused by IR radiation from other wavelengths. (A24306-07) Furry, however, selected a filter bandwidth that was wider than necessary to detect a single gas of interest, precisely in order to detect multiple gases of interest simultaneously, and using a single filter configuration. (A24226-31)

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[10] During prosecution, the examiner considered the Wimmers reference (A24159-62) as the most analogous prior art reference to the pending claims. (A24169; A24197-98; A24203-06; A24226 fn.2) The Patentee submitted a declaration from Dr. Wimmers during prosecution. (A24305-09) The examiner subsequently did not make further objections based on Wimmers. (A24260; A24267; A24314; A24321) Instead, the examiner rejected the application as obvious in view of new combinations of Sato, Cole and Pundak (A24257-70; A24311-35), which were subsequently overruled by the BPAI. (A13378-85)

The second design decision – placing the single filter configuration inside the refrigerated portion of the camera – was made to minimize IR radiation emitted by the filter itself, which otherwise would interfere with the detection of IR absorption within the specific wavelengths of interest. (A88-89 5:34-6:64; A20204-7 ¶¶46-52)

It is true, as FLIR argued to the PTAB below, that the benefits of cold filtering were known in the prior art. *See, e.g.* A14021. But it was unknown in the art, or to experts in the field, to construct an infrared imaging system with a ***single narrow bandpass filter configuration*** located in the refrigerated section along with the detector to image gas. (A6996-97 39:14-40:23; A7020 63:11-16; A7036-37 79:18-80:8; A20339-40 ¶¶347-349; A24307-08) As explained by Dr.Wimmers in his prosecution declaration, a POSITA at the time would have understood that a separate narrow filter was required for each chemical of interest. (A24305-24308) Because the refrigerated Dewar of the Merlin-MID is sealed upon manufacture, a passive-IR camera with a single narrow passband filter inside the refrigerated section was thought to have been useful only for identifying a single chemical of interest. (*Id.*) A POSITA at the time simply did not think of or attempt to construct a single-purpose, unmodifiable device – particularly given that such a camera would cost many tens or hundreds of thousands of dollars to manufacture. (A15518

¶¶92-93; A24306-08; A20339-40 ¶¶346-349) Instead, all known prior art references with narrow filters either used multiple filters (such as Wimmers' use of a filter-wheel), or else placed a single filter outside the refrigerated section, such as with a warm-filter screwed onto the lens cap, or other lens adjustments. (A15401; A23723-31; A24593; A20340-45 ¶¶350-361)

To build his prototype Hawk, David Furry provided his custom filter specifications to FLIR (Indigo at that time) for building a customized version of Indigo's Merlin-MID thermal imaging camera. (A14016-18 ¶¶29-33) As previously discussed, the unmodified Merlin-MID's standard filter, located in the refrigerated portion, had a 2-micron-wide passband centered between 3-5 microns. Furry's custom Hawk, however, was built with a carefully chosen narrow filter having a passband of approximately 100 nanometers, centered at the 3.3-micron wavelength. (A14017 ¶31; A22300-01) Rather than adding a screw-on warm filter to the Merlin-MID, Furry instead custom-ordered three Hawk cameras manufactured from scratch with his carefully selected, single narrow filter located inside the refrigerated section and permanently sealed upon manufacture. (A14016-18 ¶¶29-33) The cost to custom-build the first Hawk alone was over $60,000.00. (A23711-12)

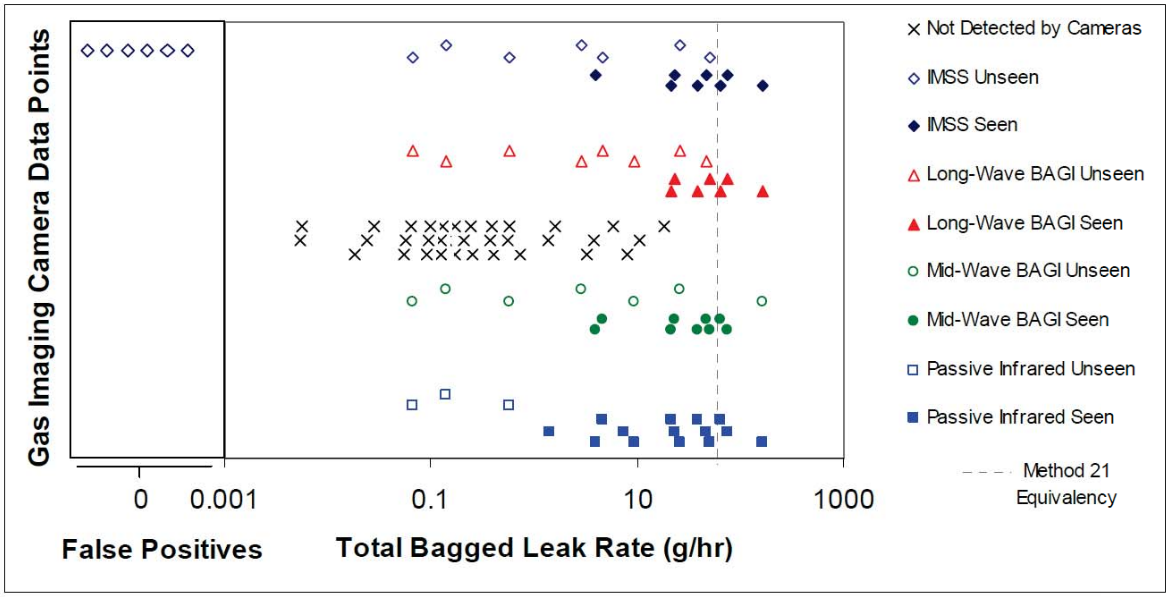
FLIR submitted sworn evidence below stating that other customers, prior to Furry, had ordered custom Merlin-MID cameras using narrow passband filters in the cold section. FLIR senior scientist and long-time employee Dr. Austin Richards (who worked at Indigo when Furry ordered his Hawk cameras), testified: "[T]here were other occasions where Indigo did replace the standard Merlin-MID filter with a narrow bandpass filter." (A7943 ¶12; A21680-83 125:23-128:19) Under cross-examination, however, Dr. Richards disclaimed his sworn declaration testimony and admitted that ***it was not true.*** (A21705-06 150:17-151:19) Dr. Richards first admitted that the word "narrow" bandpass filter in this context would ordinarily mean a filter with a bandpass of approximately 100 nanometers. (A21699-705 144:20-150:11; A21952) Using his ordinary definition of "narrow," he confirmed that his declaration testimony was not true. (A21705-06 150:17-151:19) Richards was given the opportunity to inspect a spreadsheet showing the specification of every Merlin-MID camera sold by FLIR, both before and after Furry's Hawk cameras. Following his review of the spreadsheet, he confirmed that David Furry was the ***first*** and ***only*** FLIR customer ***ever*** to order a Merlin-MID camera with a narrow passband filter located in the cold section. (A21706-709 151:20-154:18) Aside from David Furry, the narrowest custom filter placed in a Merlin-MID had a passband of 1 micron (1000 nanometers). (A7942 ¶10) Richards' deposition testimony corroborated the recollections of Dr. Parrish, that no one at Indigo prior to David Furry had ever conceived of LDAR as a potential application for the Merlin-MID camera. (A15532; A21828-29 273:7-274:17; *see also* A21815-21817 260:22-262:4; A21822-23 267:19-268:21 *comparing* A21996-22021 *with* A21965-21995).

FLIR further submitted sworn testimony, also from Dr. Richards, suggesting that he – not David Furry – originally conceived of the idea of placing the narrow filter inside the refrigerated section of the Merlin-Mid camera. (A7976-77 ¶28) Under cross-examination, however, Richards ***disclaimed having conceived of this idea*** (or any aspect of the Hawk camera), and stated that his memories of the events recounted in his declaration were “not terribly vivid.”(A21826 271:4-271:17; A21834-35 279:25-280:3) Incredibly, two weeks later, FLIR witness Dr. James Woolaway (co-founder of Indigo and long-time FLIR employee) continued to insist that Dr. Richards had conceived of the idea rather than David Furry, despite Richards’ disavowal. (A23037-43 209:18-215:13)

3. The Hawk Camera Demonstrates Its Success at Detecting Leaks in the Field, Under Real-World Conditions.

Prior to the “Scan Off,” David Furry had started a business surveying petrochemical facilities for leaks, using a Hawk camera mounted to a helicopter. (A13373; A17565; A24247) His company was the only one to offer similar LDAR services at the time. (A16131 ¶69) The Hawk's true coming-out party, however, occurred at the API's "Scan Off" field trials in early 2004. (A13396; A17619-22) Furry was invited to demonstrate his custom-modified Merlin-MID camera alongside three other systems – including an active-IR ("BAGI") system designed and demonstrated by Dr. Kulp himself, author of the Kulp reference. (*Id.*) The results of the trials are reported in the Environ report with the following table:

Exhibit 4-3. Performance Summary of Infrared Cameras.



(A13505)

The results for each tested system are reported with different shapes and colors, with Furry's Hawk camera ("Passive Infrared") represented by blue squares along the bottom of the table. Hollow squares represent unseen leaks, and filled squares represent successfully detected leaks. The numbers from left to right along the bottom of the graph represent the leak rate. Leaks to the left are smaller (lower volume), and leaks to the right are larger (higher volume). (*Id.*)

As can be seen, the Hawk camera had the lowest detection threshold, and also demonstrated a 100% success rate above its detection threshold – i.e. an ability to successfully image ***every*** leak above the threshold, with no false positives. (*Id.*; A17621-23; A16127-31 ¶¶54-64,70) Each of the other tested systems missed some leaks falling above the camera's own detection threshold. (*Id.*)

The scientists coordinating and participating in the "Scan Off" immediately appreciated the significance of these results, and the implications. David Furry had solved the technical problem of adapting an imaging device for real-world LDAR, when the entire petrochemical industry had been unable to do so. (A16130 ¶65 ("Those of us on the API team studying the problem for numerous years thought, 'This is the best thing we've ever seen!'"); A15529-30 ¶¶137,142-146; A17620-17622 ¶¶23,26; A17628 ¶43)

Despite the Hawk's impressive results, and the near-consensus among participants that Furry and his Hawk camera had demonstrated a significant technical achievement, Dr. Kulp continued to remain skeptical that Furry's passive-IR system would work without a sufficient Delta-T, under real-world conditions. (A17628, A17634-35 ¶¶42,55; A16130 ¶67) But, "[Dr. Kulp's] theory was disproven during laboratory testing." (A17628 ¶42)

4. The Hawk Camera Revolutionizes LDAR for the Petrochemical Industry

The API participants moved quickly to promote commercialization and adoption of Smart-LDAR based upon Furry's Hawk camera. (A16131-16133; A17631-35) Based on the success of Furry's demonstration, in February 2005 the API LDAR committee sponsored a trip for David Furry to go to Europe and demonstrate the Hawk camera for the rest of the world. (A17629 ¶46) The API drafted an alternative work practice to Method 21, permitting the use of optical imaging for LDAR and convinced the EPA to adopt the alternative work practice as a result of the "Scan Off" field trials.[11]

Indigo/FLIR[12] quickly appreciated the commercial opportunity presented by Furry's technical achievement and the novel specifications of the Hawk. (A22484-

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[11] The EPA's alternative work practice is not limited to a particular type of optical imager, but the record reflects that the EPA's alternative work practice was drafted as a response to the results obtained by the Hawk. (A15527 ¶128; A17630-31 ¶¶48-49)

[12] FLIR's purchase of Indigo in early 2004 occurred close in time to the Scan Off, and Furry's success at solving this technical problem was first appreciated by the Indigo/FLIR executives during their time of transition from Indigo to FLIR.

85) Indigo/FLIR had not previously engaged in LDAR research, and did not make or sell a camera suitable for LDAR. (A17532 ¶35; A16133 ¶77; A17632 ¶52) But after learning of the Hawk's success at the "Scan Off," Indigo/FLIR senior executives immediately sought to develop a special-purpose LDAR camera. (A17531-34 ¶¶31-38; A22481-85; A22506-7; A22479-80) To do this, FLIR entered into a business development licensing agreement with Furry, and together Furry and FLIR set out to create a new product market for the camera. (A22484-85; A23979-99) Their product was known as the GasFindIR – a passive-IR camera that essentially was an exact copy of Furry's Hawk, with the same single, narrow filter configuration fixed inside the refrigerated section of the camera. (A23909; A23913; A23929-30; A23933; A23944-45; A23947; A17632 ¶52; A16134 ¶¶78-79) FLIR marked the camera with Furry's then-pending patent application number, informed its customers of the intellectual property, and used its license to Furry's patent application to stifle potential competition. (A23947; A23944)

The GasFindIR was an immediate commercial success. (A17579-90; A17591-609) FLIR soon found itself with a near-monopoly in this new product market (LDAR optical imagers) – a position that it maintains to this day. (*Id.*) Practically every petrochemical facility in America today has a passive-IR LDAR camera on site, with most of those devices being a GasFindIR or other FLIR equivalent camera (the "GF Series"), having filter specifications and placement identical or substantially similar to Furry's original Hawk prototypes. (A16134 ¶¶78-79; A17632 ¶52; A23913) While petrochemical facilities still use Method 21 for purposes of complying with a court consent decree, for practical purposes passive-IR imaging using cameras substantially identical to the Hawk has replaced Method 21 as the industry's best and preferred practice for LDAR. (A7257-7262)

D. Overview of the Patents at Issue.

Furry filed three provisional patent applications prior to his participation in the "Scan Off," the first of which was filed on June 11, 2003. (A52) He filed a PCT application on April 26, 2004. (*Id.*) His patent application spent almost nine years in prosecution (including an appeal to the BPAI), before the '496 Patent issued on June 5, 2012. (*Id.*) The '813 Patent issued as a continuation on April 23, 2013. (A102)

1. The Allowed Claims.

All claims of the '496 Patent are method claims, with Claim 1 being representative. All claims of the '813 Patent are apparatus claims, with Claim 1 being representative. This appeal brief will limit its discussion to the independent claims because LSI did not make patentability arguments specific to any of the dependent claims in the IPRs below.

The independent claims all share certain critical claim elements describing the claimed passive-IR camera (or its method of use) for detecting gas leaks. Each claim describes a passive-IR camera system with a lens, a refrigerated portion with an interior, a fixed, single filter configuration, and an infrared sensor located inside the interior of the refrigerated portion.

Each independent claim requires a “single filter configuration” “fixed” along the optical path between the lens and the infrared detector. This limitation was added during prosecution to distinguish prior art using multiple filters (such as Wimmers’and Sato’s filter wheel), or Sato’s variable (tunable) filter configurations. (A24218, A24226-27; A24272; A24281-82; A13383-84)

Each claim requires that the single filter configuration be fixed and located inside the refrigerated portion of the camera. This limitation distinguishes the claims from prior art that used warm filtering, such as Strachan. (A2859, Figure 3) Each independent claim also requires that the single filter configuration be fixed along an optical path between the lens and the infrared sensor device (i.e. the infrared detector). This limitation further distinguishes the claims from prior art that used a rotating or adjustable filter wheel that did not fix a single filter configuration along the optical path (such as Wimmers) or changed the bandwidth in a variable configuration (such as Sato). (A24218, A24226-27; A24272; A24281-82; A13383-84; A24305)

Significantly, each independent claim also requires that the single filter configuration have a ***minimum*** bandwidth ("at least about 100 nanometers" in '813 Patent Claim 1 or "at least about 200 nanometers" in '496 Patent Claim 1). This claim element relates to the camera's ability to detect multiple gases of interest, and distinguishes the claims from prior art that used "extremely" narrow filters to identify the presence of a single gas of interest. (A24231; A24305-07) To allow the camera to detect multiple chemicals of interest, the claims further require that the single filter configuration have a passband wherein at least part of the passband is within the absorption band for each of the predetermined chemicals of interest.

Importantly for purposes of this appeal, the claims do not expressly set forth a numerical limitation on the passband width for the single filter configuration. Instead, the claims impose a functional limitation that has the effect of imposing an upper limit on the passband width. While the claims use slightly different language for this element, each independent claim contains certain limitations requiring that the claimed camera "***produce a visible image*** of the chemical emanating from the component under ***variable ambient conditions*** of the area around the leak." Because of the "wash out problem" previously discussed, when the passband is too wide, the camera will be unable to produce a visible image of a leak under variable ambient conditions, and thus would not fall within the scope of the claims. (A24307; A7004-5 47:21-48:20; A15019-20 ¶¶25-27; A17524-25 ¶12; A20242 ¶122)

The limitations that require producing an image under "variable ambient conditions" or "normal operating conditions" are critical to understanding the claimed inventions at issue. In short, these limitations require the claimed camera be capable of solving the technical problem addressed by the patents. *See* Sections VI(C)(2) and VI(C)(3), below. These limitations were added during prosecution to distinguish the claimed invention from prior art that could only image a gas and detect leaks under a limited range of conditions (principally, where the background temperature supplied a sufficient Delta-T), or where the art required an adjustable or tunable filter or filter wheel (such as Sato). (A24230-31; A24272-73; A24285-87) All known prior art references were capable of imaging, to a limited degree, gases and detecting leaks - but ***only*** within a narrow range of ambient conditions, such as a high Delta-T (and not under normal, uncontrolled ambient conditions). *See* Section IV(B).

2. Prosecution History.

Over more than nine years, the patents at issue were rigorously examined. Furry's prosecution required an appeal to the Board of Patent Appeals and Interferences ("BPAI"), and he succeeded in winning a reversal of the examiner's §103 rejections. (A13378-85) The BPAI found that the prior art failed to teach or disclose "an infrared camera system containing a single filter configuration that visually detects a leak under variable ambient conditions." (A13384) Upon remand, the applicant amended the claims to cure a §112 rejection, and the '496 Patent claims were then allowed. The '813 Patent claims were further examined and issued on April 23, 2013.

E. Overview of the Asserted Prior Art.

Because LSI's appellate arguments focus only on the challenged independent claims, LSI will only discuss prior art that was asserted below against the independent claims. For each alleged ground of unpatentability, FLIR asserts either the Merlin Brochure (A2852-57) or the Merlin User Guide (A2883-937) as a primary reference, and suggests a proposed modification of the described Merlin-MID camera in combination with the optical filter disclosed in either Strachan (A2858-64) or Kulp (A2938-47).

1. The Merlin Brochure and the Merlin User Guide.

The Merlin publications describe the same Merlin-MID passive-IR camera that David Furry modified to create his Hawk prototype. (A88 6:19-24)[13] The Merlin-MID is a general-purpose thermography device, intended to image objects by detecting thermal differentials. (A17527 ¶¶19-20; A21807 252:16-255:1) It was designed and marketed for applications such as thermal imaging, surveillance, night vision, etc. (A17527 ¶¶19-20; A21807-10 252:16-255:1) To accomplish this purpose, the Merlin-MID is outfitted with a cold filter (located inside the sealed Dewar flask) having a 2-micron (2000 nanometer) wide passband centered between 3-5 microns on the electromagnetic spectrum. (A2857; A17524-26 ¶¶11-12; A21803-21805 248:12-250:20)

The Merlin-MID is capable of imaging a gas ***only*** when there is a sufficient Delta-T (temperature contrast between the gas and background). Without the required Delta-T, it cannot image a gas at all. (A17524-25 ¶12; A15512-13 ¶¶68-

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[13] LSI contends that FLIR has not met its burden of proof to show that the Merlin User Guide qualifies as prior art. FLIR originally offered sworn testimony that the User Guide was publicly available on the Internet, but that testimony proved to be untrue. (A3223-24 ¶8; A21731 182:3-21; A22712-15 80:23-83:14) FLIR now contends that the User Guide qualifies as prior art because it was shipped to customers when they purchased a camera costing more than $54,000.00. (A23711) LSI argued below that this is insufficient evidence of public availability. (A1014-15) The Board sided with FLIR on this issue. (A21-23)

70; A7937-36 ¶6; A21757-58 202:1-203:4) Even with a sufficient Delta-T, the viewer would not know what ***particular molecule*** is being imaged. The viewer would simply see something hot against a cold background – the Merlin-MID simply detects temperature differences. (A17524-25 ¶12; A21742-45 187:6-188:8, 189:22-190:25; A15512-13 ¶70) The Merlin-MID is not capable of performing absorption spectroscopy or detecting the presence of particular gases of interest because of the "wash out" problem – its filter is too wide. (A17524-25 ¶12; A15520 ¶99; A24306; A7004-5 47:21-48:20; A15019-20 ¶¶25-27; A20242 ¶122) For that reason, it was not intended as an LDAR device, and has never been marketed for this application. (A17524-25, A17526-27 ¶¶12,16, 19-20; A21828-29 273:7-274:17)

2. Strachan.

Strachan discloses a passive-IR camera that uses a ***warm*** filter (i.e. outside of the refrigerated section). (A2859 Fig. 3; A15023-15025 ¶¶41-42,47-48) The Strachan reference discloses the use of two filters – a 500nm filter and a 1000nm filter. (A2859-60) It teaches away from narrow filtering by stating that as between the two filters, the 1000nm filter is expected to demonstrate superior results due to higher sensitivity. (*Id*.)

In its IPR petitions, FLIR does not specify which of the Strachan filters (500nm or 1000nm) should be used for purposes of the alleged combination with the Merlin-MID references. (A240-242; A24886-24891; A2825-2826 ¶80; A26231 ¶59; A1695-1696 67:11-68:17)

Strachan's experiments demonstrate that his camera setup is able to detect leaks only under limited ambient conditions – particularly, where the atmospheric temperature is at least 303K (~86F). (A2862-63 (discussing Fig. 10); A15024-26 ¶44-46,49-52; A15515-17) In other words, the Strachan camera would not be useful for detecting gas leaks during cold atmospheric conditions. According to Strachan co-author Dr. Hossack, the Strachan paper does not disclose a system that is capable of imaging gases or detecting leaks under variable ambient conditions. (A15025-30 ¶¶51-67)

3. Kulp.

The Kulp reference describes a field test comparison between an active-IR camera ("BAGI") and a passive-IR camera. (A2938-47) The passive-IR system of Kulp is equipped with a filter having a 570nm passband, centered between

10300nm and 10870nm.[14] (A27588; A2940 Figure 2) Kulp states that this is a "cold-filter," but the reference does not specify whether the filter is placed inside the refrigerated section, or if it is cooled in another way (for example, by placement adjacent to the refrigerated portion). The Board rejected Kulp as an anticipatory reference for this reason. (A378)

From his field tests, Kulp concludes that the "passive imager exhibited significant variations in its performance. Sensitivities about a factor of 2 worse than the BAGI were observed as moderate (5-7 C) air-target temperature differences. At lower differences the signal deteriorated substantially." (A2945) In other words, Kulp's passive-IR camera could not image a gas when the Delta-T was lower than 5-7 C. Kulp concludes that passive-IR remains interesting for further research, but "[i]ts use must, however, be accompanied by the assumption that the required temperature and/or emissivity differences between the gas and background will always exist." (*Id.*) Without a sufficient Delta-T, Kulp's passive-IR camera will not produce a visible image of the gas. (A20310-12 ¶¶274-279; A15510-12)

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[14] Kulp reports the passband in "wavenumbers," which can be converted to nanometers. There is no dispute in this case regarding the passband specifications of the Kulp filter.

V. SUMMARY OF THE ARGUMENT

The Board's Final Written Decision ("FWD") contains significant legal errors, and many of its critical fact findings are not supported by substantial evidence. The Board adopted erroneous and overbroad constructions of the terms "leak," "variable ambient conditions," and "normal operating conditions." These claim construction errors are a reflection of the Board's failure to appreciate the technical problem addressed by the patents or the true state of the art at the time of the invention – i.e., the problem of adapting known imaging devices for LDAR use in the real-world, under normal and variable (uncontrolled) conditions.

The Board erred in finding that the alleged combinations of references meets claim limitations requiring detection of a "leak" under "variable ambient conditions" and/or "normal operating conditions." The Board further erred in finding a motivation to combine the references. The Board also erred by finding that the objective evidence of non-obviousness has no nexus to the challenged claims, and thus refusing to give any weight to the compelling objective evidence, such as long felt need and failure of others.

The Board's obviousness determinations are erroneous and must be reversed. Remand is not appropriate given the factual record of this appeal. Judgment should be entered in favor of LSI, dismissing FLIR's IPR petitions.

VI. ARGUMENT

A. Standards of Review.

In any appeal from the PTAB, this Court reviews the PTAB's factual findings for substantial evidence, and the PTAB's legal conclusions are reviewed de novo. *See Redline Detection, LLC v Star Envirotech, Inc.*, 811 F.3d 435; 2015 U.S. App. LEXIS 22897 at *28 (Fed. Cir. 2015). "A finding is supported by substantial evidence if a reasonable mind might accept the evidence in support of the finding. If the evidence in [the] record will support several reasonable but contradictory conclusions, [the Court] will not find the Board's decision unsupported by substantial evidence simply because the Board chose one conclusion over another plausible alternative." *Id.* (internal citations omitted).

For claim construction, the Board's ultimate claim constructions are reviewed de novo, with any underlying factual determinations involving extrinsic evidence reviewed for substantial evidence. *See Microsoft Corp. v. Proxyconn, Inc.*, 789 F.3d 1292, 1297 (Fed. Cir. 2015). On the ultimate issues of patentability and obviousness under §103, the Board's findings are conclusions of law that are reviewed de novo, with the underlying issues of fact reviewed for substantial evidence. *See Redline Detection*, 2015 U.S. App. LEXIS 22897 at *28-29.

B. The Board Misapprehended the Nature of the Technical Problem Addressed by the Patents. The Board's Statement of the Technical Problem is Not Supported by Substantial Evidence.

FLIR's Petitions and Reply focused on whether the alleged combination of references would be able to "image a gas." The Petitions purposefully glossed over whether the combinations would be able to detect an unknown leak, under normal and variable ambient conditions. Instead, FLIR merely contends that the combination would be able to image a gas under "various" (not variable) ambient conditions. (A238-39; A24883-84; A27594) According to FLIR: "[t]he claims merely require that gas is imaged under ***<u>some</u>*** normal and variable ambient conditions." (A1180) For example, FLIR contends that Kulp alone meets this limitation because, given a sufficient Delta-T, Kulp's passive-IR system could image a gas at two different times of day. (A27594; A1186)

FLIR's interpretation of the claims is far removed from the problem that Furry and the petrochemical industry were addressing. A camera capable of detecting leaks only under "some" normal operating conditions would have been deemed not useful at the API's "Scan Off." (A15511 ¶67) As previously discussed, prior art passive-IR cameras were able to reliably image gases only when there was ***a sufficient Delta-T*** greater than what is often present under normal operating conditions. Furry and the industry were trying to adapt and improve these known systems to make them useful ***in the field*** – for identifying unknown fugitive emissions ("leaks") under the normal and variable (uncontrolled) conditions common to petrochemical facilities. *See* Section IV(A), above.

During the oral argument, FLIR's counsel repeatedly emphasized that LSI's patents are obvious because prior art cameras were able to image gases, ***so long as there is a sufficient Delta-T.*** (A1645 17:4-5; A1650 22:13-19; A1656-1657 28:18-29:6) Counsel's statements are firm proof that FLIR does not read the claims to coincide with the technical problem that Furry and the industry were trying to solve in the real world. (A1670 42:5-24)

In its FWD, the Board similarly misstated the nature of the technical problem addressed by the patents. The Board stated: "Contrary to LSI's position that the Furry camera was the only solution that worked at field trials of leak detection systems . . . the evidence shows that all of the tested imaging systems successfully ***imaged gas***… . The record shows that Kulp and Strachan both successfully ***imaged gas*** using passive IR cameras with appropriate cold filters." (A42) The Board viewed the technical problem as simply imaging gasses under "some" operating conditions. (A41) The Board thus failed to appreciate the technical problem being addressed by David Furry and the industry.

C. The Board Adopted Erroneous Claim Constructions.

The Board's FWD is premised upon at least two erroneous claim constructions, as discussed below.

1. Legal Standards for Claim Construction.

In IPR involving an unexpired patent, the Board gives the claims the "broadest reasonable construction in light of the specification… ." 37 C.F.R. §42.100(b).[15] The broadest reasonable construction, however, is still bounded by what is legally correct and supported by the intrinsic record. As recently explained by the Federal Circuit:

> That is not to say, however, that the Board may construe claims during IPR so broadly that its constructions are unreasonable under general claim construction principles… . [T]he protocol of giving claims their broadest reasonable interpretation … does not include giving claims a legally incorrect interpretation… . Rather, claims should always be read in light of the specification and teachings in the underlying patent. The PTO should also consult the patent's prosecution history in proceedings in which the patent has been brought back to the agency for a second review... . Even under the broadest reasonable interpretation, the Board's construction cannot be divorced from the specification and the record evidence ... and must be consistent with the one that those skilled in the art would reach. ***A construction that is unreasonably broad and which does not***

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[15] Like it did below, LSI hereby objects to the Board's application of the broadest reasonable construction standard. (A969) The Board's claim constructions, however, are erroneous under both the PTAB's standard and also the district court *Phillips* standard.

> ***reasonably reflect the plain language and disclosure will not pass muster.***

Proxyconn, 789 F.3d at 1298 (emphasis added, internal quotes omitted).

2. "Leak"

The term "leak" or "gas leak" appears pervasively throughout the claims, and its meaning is essential to a proper understanding of claim scope. LSI contends that the term "leak" means ***unintended or fugitive emissions*** and does not encompass intended or known emissions. (A975-79). FLIR, on the other hand, contends that "leak" encompasses both ***intended and unintended*** emissions. (A211-13). The Board agreed with FLIR, and adopted a broad construction of "leak" encompassing both fugitive emissions ***and also*** known or expected emissions. (A12)

Both FLIR and the Board agree that the Board's construction is broader than the ordinary meaning of this term, as understood by a POSITA. The ordinary meaning of "leak" to a POSITA is limited to a fugitive or unintended emission. (A20271-72; A18149-50 174:24-175:19) The technical field of the invention relates to ***leak detection*** and repair ("LDAR"), a discipline that is inherently interested in finding fugitive, unintended emissions.[16] This is apparent from a

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[16] The word "repair" is also telling; one does not "repair" an intended emission.

reading of the background section of the patent. (A86 1:31-58) It also is apparent from the prosecution history. (A24229-30) It is clear from the 2004 Environ Report, for example, that the patent's use of the term "leak" is consistent with the way the term was used in the LDAR field at the time of the invention. (A13395-96, A13401, A13407-10) Ample additional evidence confirms that the ordinary and customary meaning of "leak" encompasses fugitive emissions, but does ***not*** encompass known or intended emissions. (A15502-4 ¶¶34-38; A16111-13 ¶¶9-13; A17614 ¶9) In ordinary speech, one does not turn on the water faucet and say "my faucet is leaking." The faucet is "leaking" if it drips when it is not supposed to, or if water squirts out the side of an unsealed pipe.

To support its departure from the ordinary meaning of the term "leak," the Board cites two sentences from the patent specification, neither of which use the word "leak" at all. (*See* A11 (citing Patent at 12:17-25, 20:28-31))

These two sentences do not support the Board's construction; and they certainly do not provide a special definition contrary to ordinary meaning. The sentence at 12:17 deals with the ***types of components*** that can be inspected by the invention. The fact that some components (such as a flare or exhaust) can have both intended and unintended emissions does not make the intended emissions a "leak." It was well known in the art that components such as exhausts or flares can have both intended emissions, and also unintended fugitive emissions. (A18033-34 58:7-59:9) A POSITA would refer to the latter (and not the former) as a "leak." The sentence at 20:28 similarly does not support the Board's construction. It is related to a vent, which also can have both known and fugitive emissions, and the sentence cited does not directly address detection of imaging of known emissions from a vent. (*Id*.)

Moreover, the Board's construction is inconsistent with the remainder of the specification. After the sentence the Board cites, the patent specification provides a lengthy explanation of various ***uses*** of the claimed invention, and every single described use involves the detection of ***fugitive*** (unknown) emissions. No described use of the invention involves imaging known or intended emissions. (A91-96 12:26-21:15) Throughout the specification, the patent ***repeatedly*** uses "leak" to refer to an unintended (fugitive) emission. The patentee's intended meaning of "leak" also is clear from the prosecution history, where known emissions are distinguished from unknown hydrocarbon leaks requiring detection. (A24229-30)

The evidence cited by the Board – two isolated sentences from the specification describing the types of components that can be inspected – is not sufficient to support the Board's broad construction that substantially deviates from the ordinary and customary meaning. *See Straight Path IP Group, Inc. v. Sipnet EU S.R.O.*, 806 F.3d 1356, 1361 (Fed. Cir. 2015).

The Board's erroneous claim construction for "leak" is significant because it fundamentally changes the nature and scope of the claims from "detecting a leak" to "imaging a gas." This is erroneous and must be reversed. *See id.* at 1361-64; *Proxyconn*, 789 F.3d 1292 at 1300. *See also Schott Gemtron Corp. v. SSW Holding Co.*, 612 Fed.Appx. 614 (Fed. Cir. 2015) (affirming PTAB's construction of "spill" to include unintentional release of liquids, but excluding intended releases - IPR2013-00358, Paper 106 at 6-8).

3. "Variable Ambient Conditions" and "Normal Operating Conditions"

Each of the independent claims contains limitations concerning "variable ambient conditions" or "normal operating conditions" or both. There is some variation in claim language, but in each instance these terms are used to describe the conditions of the area around the leak. The following claim elements are representative:

- "filtering an infrared image associated with the area of the gas leak under ***normal operating and ambient conditions for the component*** " and "electronically processing the filtered infrared image . . . to provide a visible image of the gas leak under ***variable ambient***

conditions of the area around the leak" and "visually detecting the leak based on the visible image under the ***variable ambient conditions***." ('496 Patent Claim 1, emphasis added)

- "a processor that can process a signal representing the filtered infrared image . . . to produce a visible image of the chemical emanating from the component under ***variable ambient conditions*** of the area around the leak." ('813 Patent Claim 1, emphasis added)

LSI urged the Board to adopt a construction of "variable ambient conditions" and "normal operating conditions" that excludes artificially constrained or controlled conditions, such as in a laboratory environment. (A969-71; A1672-75 44:16-47:23). LSI's construction would limit the claims to embodiments that actually solve the problem addressed by the patents – detecting gas leaks under real-world variable conditions. *(Id.*)

The Board rejected LSI's construction, stating: "We are not persuaded that the patent claims' reference to variable ambient conditions are limited to 'real-world' conditions... . [W]e are not persuaded by LSI's attempt to exclude controlled environments from the claimed ambient conditions... . We find no support for LSI's contention that 'variable ambient conditions' or 'normal operating in [sic] variable ambient conditions' is limited to instances that are not constrained or controlled in some manner." (A13-14)

Indeed, the claim construction adopted by the Board ***eliminates*** the word "variable" altogether. The Board's construction is: "being able to produce a visible image under the ambient conditions of the area around the leak." (A14) The Board's comparison of the claims to the prior art made clear that the Board's construction is satisfied if a system is able to image a gas under ***any two different conditions***, even if those conditions are only slightly different (e.g., even one degree different in temperature). (A32-33) In the FWD, the Board literally changed "variable" to "various" – *i.e.* any two possible variations. (A32 ("We find that Strachan discloses that practical quality images of hydrocarbon gas can be obtained at various temperatures.")) The Board's error is in accord with FLIR's petitions, which similarly changed "variable" to "various" in assessing the prior art. (A238-39; A24883-84; A27594) The Board's construction is erroneous.

The Board's construction is contrary to the ***entirety*** of the specification. It disregards the technical problem of the patent – detecting leaks under normal and variable operating conditions in the real-world. Throughout nearly ***nine columns*** of specification, the patent describes many use-case applications of the invention, ***none*** of which disclosed uses allowing for the constraint or control of the normal ambient conditions around the leak. (’496 Patent 12:26-21:15) Yet, the Board concludes: “We are not persuaded that the patent claims’ reference to variable ambient conditions is limited to ‘real-world’ conditions.” (A13)

The Board’s construction is also inconsistent with the prosecution history, where these limitations were added to distinguish prior art that could image gases only under constrained or controlled conditions, or else a narrow range of conditions. (A24230-31; A24273; A24285-87) These same limitations were important to the BPAI during the prosecution appeal for distinguishing the prior art. (A13884) There is no ambiguity in the prosecution history: “variable ambient conditions” and “normal operating conditions” were added to the claims to convey that the conditions around the leak are not being constrained or controlled. (A20275-82 ¶¶195-208)[17]

All credible evidence of record supports LSI’s claim construction. LSI’s claim construction is consistent with the ordinary and customary meaning of the terms, as understood by a POSITA at the time and grounded in the intrinsic evidence. (A24230-31; A24273; A24285-87; A15503-04 ¶¶37-38; A15514 ¶74;

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[17] Dr. Sandsten’s petition declarations (all ***five*** of them) make no mention of the ’496 Patent prosecution, and he admitted in deposition that the prosecution history played no role in shaping his opinions. (A18004-07 29:12-31:1, 32:13-32:23)

A20275-82 ¶¶195-208; A21627-29 77:2-79:24) The Board provides no credible justification for its construction. The Board does not cite any particular portion of the specification as providing a special definition, and the Board cites nothing from the prosecution history. The Board's erroneous claim constructions are unreasonably broad, and again divorce the claims from the technical problem being addressed.

D. The Board Erred in Finding That the Suggested Combination of References Discloses the Claim Terms that Require Detecting a "Leak" or Producing a Visible Image Under "Variable Ambient Conditions" and/or "Normal Operating Conditions."

With respect to the independent claims, the Board found that each suggested combination of references (Merlin Brochure combined with Strachan for the claims of the '469 Patent, and the Merlin User's combined with Kulp for the claims of the '813 Patent) discloses the claim elements that require producing a visible image and detecting a leak under "variable ambient conditions" and/or "normal operating conditions." (A30-35) FLIR, however, offered ***no evidence whatsoever*** in support of these claim elements, whatever they are construed to mean. FLIR easily could have performed testing (as it did with its GasFindIR) to determine whether the proposed combination would even work to detect leaks under variable ambient conditions. (A23951-78) But FLIR chose not to do that, and as a result FLIR's proof is simply incomplete.

The unmodified Merlin-MID camera (as described in the printed Merlin references) is not capable of detecting gas leaks under variable ambient conditions. (A17523-26; A15514-15 ¶¶74-78) Optimized for thermography, it uses a wide filter with a 2 micron (2000nm) passband. While it can image a gas when there is a sufficient Delta-T, it cannot detect the presence of ***particular*** gases of interest, and it cannot detect gas leaks under variable ambient conditions because of the "wash out" problem. *See* Section IV(E)(1), above.

To remedy this deficiency in the Merlin-MID as a prior art reference, FLIR asserts two §103 combinations of the Merlin-MID with the narrower filters of Strachan (500nm and 1000nm) and Kulp (570nm). Strachan's system, however, was unable to image a gas ***unless there is a sufficient Delta-T***. *See* Section IV(E)(2). Strachan concludes that the atmospheric temperature must be at least 303K (86 F). It is incapable of imaging gases under variable ambient conditions. (*See id.; see also* A15025-15030 ¶¶51-67) Similarly, the Kulp passive-IR system is able to image a gas only if the background temperature is warm enough to create a sufficient Delta-T between the gas and the background. *See* Section IV(E)(3), above. Kulp's passive-IR camera is unable to image gases or detect leaks under variable ambient conditions. (*Id.*)

Would FLIR's suggested combinations (Merlin + Strachan, or Merlin + Kulp) perform any better, and be able to detect leaks under normal and variable ambient conditions? The answer is that ***no one knows*** – certainly not based on the evidentiary record before this Court. No one knows if cold-filtering alone would remedy the deficiencies described in Strachan or Kulp. In all likelihood, it would not – because the disclosed filters are too wide, and the image would wash out. (A15025 ¶49 ("Strachan does not discuss the possibility that coverage by a filter may be too broad for effective detection"); A15513 ¶71) No one knows for sure, because FLIR made ***no attempt whatsoever*** to offer evidence to show whether the alleged combinations would satisfy the claim limitations related to detecting leaks and imaging gases under normal operating conditions and variable ambient conditions. (A1693-1694 65:4-66:11; A971-974) FLIR knows how to perform scientific testing to determine if a camera can image gases and visually detect leaks under variable ambient conditions. (A23951-78) But it did not, and the record is deficient as a result. The Board's findings as to these claim elements are erroneous. They are legally defective (and subject to de novo review) because they are premised upon erroneous claim constructions. The Board erroneously considered whether the combination would image a gas under "some" conditions, not under "variable" conditions. (A32-33; A41) The Board's findings also are not supported by substantial evidence because FLIR offered no proof as to these claim elements, properly construed. No matter what construction is given to "variable ambient conditions" or "normal operating conditions" – so long as these elements are not read out of the claims altogether – FLIR failed to offer any proof that the alleged combinations would satisfy these claim elements.

E. The Board Erred by Finding that a POSITA Would Have Been Motivated to Combine the References.

1. Legal Standards – Motivation to Combine.

An invention "composed of several elements is not rendered obvious merely by demonstrating that each of its claimed elements was, independently, known in the prior art." *KSR Int'l Co. v. Teleflex, Inc.*, 550 U.S. 398, 418 (2007). Rather, "to establish a prima facie case of obviousness based on a combination of elements in the prior art, the law requires a motivation to select the references and to combine them in the particular claimed manner to reach the claimed invention." *Eli Lilly & Co. v. Zenith Goldline Pharms., Inc.*, 471 F.3d 1369, 1379 (Fed. Cir. 2006). A finding of obviousness must include "articulated reasoning with some rational underpinning" supporting the combination of references, and the Board's reasoning "should be made explicit." *KSR*, 550 U.S. at 418*; see also In re Kahn*, 441 F.3d 977, 988 (Fed. Cir. 2006); *Cutsforth, Inc. v. Motivepower*, 2016 U.S. App. LEXIS 1083 *7-8 (Fed. Cir. 2016).

2. The References Themselves do not Suggest a Motivation to Combine.

The suggested combinations would require building a new Merlin-MID camera from scratch, by replacing the standard 3-5 micron filter inside the sealed Dewar with the narrower filters of Strachan or Kulp. (A20339-40 ¶¶346-349; A15030-31 ¶¶68-70) None of the prior art references of record, however, explicitly or implicitly suggest the combination of a single narrow filter fixed inside the refrigerated section of the camera, as the claims require.

The Board concluded that "[t]he preponderance of the evidence indicates that several prior art references taught putting cold filters narrowband filters [sic] inside the refrigerated portion to improve imaging of gas." (A39) This is untrue, and the Board's finding is not supported by substantial evidence. The Board cites Wimmers to support this finding. (A39) But the Board ignores: (1) Wimmers' own declaration submitted by the patentee during prosecution, stating that his article teaches the use of the narrowest possible filters, ***focused on a single gas of interest***; and (2) the fact that a POSITA at the time would not put a narrow fixed filter inside the cold section, but instead would use either a screw-on warm filter, a tunable filter, a camera lens adjustment; or a cooled filter wheel. (A24305-24308; A20340-45 ¶¶350-361; A24218-45; A24281-89)

The Board also cites the testimony of Jeff Leake, but the cited testimony concerns cold filtering for wide filters (specifically in the Amber mid-wave camera, which had a filter substantially identical to the Merlin-MID and on which Furry had originally experimented). (A4767-68 39:10-40:20; A14009-14010 ¶¶10-11; A13372; A6997-98 40:24-41:20)

The Board does not cite Strachan on this point; but Strachan also does not suggest putting a single, narrow filter inside the Dewar. Strachan uses a warm filter located outside the refrigerated section. *See* Section IV(E)(2), above. There is no suggestion in Strachan that the deficiencies in its disclosed system would be remedied or improved by cold filtering. (A15032-34 ¶¶75,79-81) The Board cites to portions of Dr. Hossack's testimony in which he states it would have been obvious to modify the Merlin-MID camera to use a narrower filter. (A36) But the Board inexplicably ignores Dr. Hossack's testimony in which he insists (like Dr. Wimmers) that a POSITA at the time would have done the modification by using a warm screw-on filter, or else a filter wheel. (A15030-39 ¶¶68-102)

Similarly, the Board does not cite Kulp as teaching a modification that would place a single narrow filter inside the refrigerated section. Like Strachan, Kulp notes the deficiencies with his passive-IR camera (requiring a minimum

Delta-T), and Kulp nowhere suggests that cold filtering would remedy these deficiencies. (A2945-46)

The Board's finding that the references themselves provide a motivation to combine is not supported by substantial evidence.

3. The Board's Findings that the Suggested Combinations Would be an "Obvious Design Choice" and an "Intended Use of Known Elements that Yield Predictable Results" are not Supported by Substantial Evidence.

The Board further found that the suggested combinations are each an "obvious design choice" and an "intended use of known elements that yield predictable results." (A39) These findings are not supported by substantial evidence.

The record shows that the combination of the Merlin-MID with a single narrow passband filter was not obvious to anyone, and no one expected or predicted the results that David Furry achieved. Indigo (later acquired by FLIR) and its founders and scientists, who designed and manufactured the Merlin-MID, at the time did not conceive of this design choice or expect the results. The deposition testimony of Bill Parrish and Austin Richards on this issue is compelling. Parrish is widely regarded as a pioneer in the field of passive-IR imaging and co-founded several of the leading infrared imaging companies. He testified that neither he nor his team at Indigo (including his subordinate, Dr. Richards) ever conceived of gas leak detection or LDAR as a suitable application for the Merlin-MID until after David Furry brought the idea to them. (A17525-27 ¶15,18; A17531-33 ¶¶33-35,37-38; A7005, A7020-22, A7035-39 48:10-20, 63:11-16, 64:18-65:10, 78:21-80:8; 81:10-82:1) Current FLIR employee (and then Indigo employee) Dr. Richards confirmed this testimony. (A21828-29 273:7-274:17) A comparison of Richards' own academic publications shows that he did not conceive of this potential application to detect leaks for the Merlin-MID until after David Furry built the Hawk prototypes. (A21815-17 260:22-262:4; A21822-23 267:19-268:21; A21996-22021; A21986)

Dr. Wimmers testified that he did not expect the results achieved by David Furry's combination of the Merlin-MID with a single narrow filter in the cold section. In Dr. Wimmers' view, this was not an obvious design choice at the time. (A24307-08) Similarly, Dr. Hossack, co-author of the Strachan reference, also provided declaration and deposition testimony stating that the suggested combination was not an obvious design choice at the time, and that the results were unexpected. (A15030-39 ¶¶68-102)

Dr. Kulp did not submit testimony in this case, but he personally observed the Hawk camera's performance at the "Scan Off." He reacted in disbelief – continuing to criticize passive-IR as a platform altogether and remaining skeptical that the Hawk camera could provide the basis for a commercially viable LDAR system. (A16130 ¶67; A17628 ¶42) We even know that FLIR's expert, Dr. Sandsten, did not think of this design choice at the time or anticipate the results that Furry achieved. Sandsten was attempting to solve the same technical problem at the same time as Furry. Yet Sandsten's solution was ineffective at the time. (A20320-23; A3330-32; A22490; A13412; A13548)

Many of the lead scientists coordinating the API's LDAR efforts and the "Scan Off" provided testimony in this case, and every one of them testified that Furry's design choices were not obvious, and that the results were not expected. (A15517-15518 ¶¶90-91).

The record is completely devoid of evidence that anyone ever conceived of this allegedly "obvious" design choice, or that anyone anticipated or predicted the results. Dr. Sandsten's "opinion" is not substantial evidence for many reasons. His declaration testimony is conclusory – unsupported by facts and data. (A2821-2822 ¶70; A26226-26227 ¶51; A29846-29847 ¶¶99-101) It is therefore entitled to no weight. *See* 37 C.F.R. §42.65(a). Sandsten also confirmed that his opinions were formed without consideration of secondary consideration evidence – including no discussion of the failure of others (including himself) to solve the problem. (A22085-86; A22210-16; A22229-30 33:6-34:18; A22210-22216 158:17-164:1;

A22229-22230 177:4-178:10) The evidence he was allowed to consider was cherry-picked by FLIR's lawyers, precluding him from considering secondary considerations such as commercial success and copying. (A18194-95 219:17-220:18) His cross-examination demonstrated that he lacked a basic familiarity with the applicable legal principles for obviousness, including the importance of secondary considerations. (A18190-18195) His testimony also confirmed his use of hindsight by using the patent as a roadmap for reconstructing the invention. (A18135-36 160:2-161:3) For all these reasons[18], Sandsten is not competent to offer expert testimony regarding the motivation to combine, and the Board erred by assigning his testimony any weight. *See InTouch Technologies, Inc. v. VGO Communications, Inc.*, 751 F.3d 1327,1351-52 (Fed. Cir. 2014) (disregarding expert testimony under similar circumstances).

Because the references themselves do not teach or suggest the alleged combinations, and because there is no evidence in the record to support the notion that the combination of references was an "obvious design choice" or that it would

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[18] It also bears noting that Sandsten's objectivity is suspect, given that he is a long-time consultant for FLIR who accepted a job for full-time employment the month prior to signing his first declaration for this case, and part of his job duties is to provide his "expert opinions" in this matter. (A18208-12 233:22-237:7)

produce "predicable results," the Board's findings are not supported by substantial evidence.

4. LSI Proved that the Suggested Combinations Would Alter the Principle of Operation and Destroy the Intended Uses of the Merlin-MID Camera. The Board's Findings to the Contrary were not Supported by Substantial Evidence.

LSI did not simply poke holes in FLIR's proof regarding the motivation to combine. Instead, LSI offered extensive testimony and evidence permitting a full *Graham* analysis, including an assessment of the full state of the art, and the true motivations of a POSITA at the time.[19] (*See generally* A20180-84) Among other things, LSI's evidence demonstrated that FLIR's proposed combinations would change the fundamental principle of operation for the Merlin-MID device, and would render it unsuitable for its intended uses. (A993-996)

"[C]ombinations that change the basic principles under which the prior art was designed to operate, or that render the prior art inoperable for its intended purpose, may fail to support a conclusion of obviousness." *Plas-Pak Industries v. Sulzer Mixpac AG*, 600 Fed. Appx. 755, 757-58 (Fed. Cir. 2013). *See also In re*

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[19] FLIR's expert (Dr. Sandsten) on the other hand, admitted in his deposition that he failed to consider critical state of the art evidence that taught away from the use of passive-IR for LDAR, such as a prominent article authored by Dr. Kulp, that Sandsten was aware of at the time of its publication (A22232-37 180:5-185:10; A22486-505)

Gordon, 733 F.2d 900, 902 (Fed. Cir. 1984) (intended purpose); *In re Ratti*, 270 F.2d 810, 813 (C.C.P.A. 1959) (principle of operation); MPEP 2143.01 V and VI.

As discussed above, the Merlin-MID was optimized for thermography. Its basic principle of operation is ***emission spectroscopy*** – i.e. detecting the emission of IR radiation hotter than the surrounding environment by temperature difference. (A17524-17528 ¶¶11-12,16,18,21; A20304 ¶258; A21803-21805 248:12-250:20; A15520 ¶99) Its performance is optimized when it is able to detect the maximum amount of IR radiation within a band that is relatively free from interference caused by absorption. *See* Section IV(C)(1) and IV(E)(1), above. For this reason, the Merlin-MID uses a wide passband (2000nm) filter centered between 3-5 micron wavelengths. *Id.* The Merlin-MID unmodified is not capable of performing absorption spectroscopy because of the “wash out” problem. *Id.*

Replacement of the Merlin-MID’s wide filter with a narrow filter (such as used by Furry, Strachan or Kulp) changes the device’s fundamental principle of operation. With a narrow filter, the camera is no longer suitable for performing emission spectroscopy. (A17526-17528 ¶16,21; A20302-6 ¶¶254-263) Instead, a passive-IR camera with a narrow filter practices ***absorption spectroscopy***, detecting the absorption of expected IR radiation within a very narrow and specific bandwidth – i.e., the reduction in the background radiation by the absorbing gas.

(A17526-17528 ¶16,21; A15021-15022 ¶¶33-37; A20302-06 ¶¶254-263; A15516 ¶86) Absorption spectroscopy is a fundamentally different principle of operation than emission spectroscopy. (*Id.*; A21803 248:12-250:20) FLIR's own documents produced in discovery show it clearly understood this distinction and explained the difference to its customers. (A24625, A24632-37) *See also* Section IV(C)(1), above.

Moreover, the Merlin-MID was designed and marketed for thermography applications such as thermal detection, surveillance, night vision – applications that required a ***highly sensitive instrument***. See Section IV(E)(1), above. When modified in the manner suggested by FLIR's proposed combinations (using the filter of Strachan or Kulp), the modified camera would no longer be suitable for these thermography applications because the broad range of IR data coming to the camera is lost – it is filtered out, making the camera a highly ***selective*** instrument instead. (A17526-17528 ¶16,21; A15021-15022 ¶¶33-37; A20302-6 ¶¶254-263; A15516 ¶86)

The Board's findings on these points are legally erroneous and not supported by substantial evidence. First, regarding the principle of operation, the Board misapplied the relevant legal standard. The Board considered the principle of operation of the Merlin-MID versus the Kulp and Strachan references to determine whether the references “teach away” from the proposed combination. (A36) That is an incorrect application of the legal standard. The question is not whether two references use a different principle of operation. The relevant question is whether the ***proposed combination*** would have the effect altering the principle of operation of the prior art device being modified. If so, under the controlling case law cited above, there is no motivation to combine. The question is not what the references teach, but instead what a POSITA would be motivated to do. Where the proposed combination would alter the principle of operation of the device being modified (here the Merlin-MID), then a POSITA would not be motivated to combine the references. (A17526-17528 ¶16,21; A15021-15022 ¶¶33-37; A20302-6 ¶¶254-263; A15516 ¶86)

Second, the Board never disputes LSI’s contention that the combination does in fact alter the principal of operation from emission spectroscopy to absorption spectroscopy. In fact, the Board’s comparison of the Merlin-MID with the Kulp and Strachan references seems to agree that they are based on different principles of operation. (A36)

Regarding the intended purpose, the Board’s findings are similarly without substantial evidence. The Board finds that the intended functionality of the unmodified Merlin-MID is to “image gases.” (A36) But the Board cites ***no***

evidence to support this conclusion. There is no dispute that the Merlin-MID was optimized for thermography, and intended for applications such as thermal detection, surveillance, and night vision. *See* Section IV(E)(1). The evidence cited above uniformly indicates that the proposed combinations (Merlin + Strachan or Merlin + Kulp) would be unsuitable for these applications. The Board's decision does not conclude otherwise. The fact that the modified Merlin-MID would still be able to "image gases" under some very limited range of conditions does not mean that the modified device would still be suitable for its intended purposes such as night vision or surveillance.

F. The Board Erred in Refusing to Give Weight to Patent Owner's Compelling Objective Evidence of Non-Obviousness, Including Long-Felt Need and Failure of Others.

The factual record of this case presents overwhelming objective evidence of non-obviousness with an undeniable nexus to the novel features of the challenged claims. Few cases present stronger objective evidence than the record of the present case. (A1018-1027) *See also* Sections IV(A), IV(B), IV(C)(3) and IV(C)(4), above.

The Board sidestepped the evidence of long-felt need and failure of others based on its erroneous view of the claims, and its erroneous and unreasonable claim constructions of "variable ambient conditions," "normal operating conditions" and "leak." (A41-46) The Board found "the challenged claims do not recite or require any specific conditions. Indeed, the challenged claims require imaging of known or unknown gas under "some" operating conditions." (*Id.* at 41) Using this faulty view of the claims, the Board rejected the evidence of long-felt need and failure of others, essentially finding that the prior art was able to solve what the Board incorrectly perceived as the relevant technical problem (merely imaging gases under "some" conditions).

The Board's conclusions are legally erroneous (and subject to de novo review) because they are premised on erroneous claim constructions. Moreover, the Board's finding that "LSI has not provided persuasive evidence showing the intrinsic nexus to the challenged claims and how the invention resolved the long-felt need" (A43) is both legally erroneous and not supported by substantial evidence.

As discussed above, since at least 1997, the entire petroleum industry (including the API, the EPA, and state agencies) had been attempting to solve the technical problem of adapting known imaging devices for LDAR use under real-world, variable conditions. *See* Section IV(A). The prior art references, the other documentary evidence, and the sworn testimony of many highly-qualified persons of extraordinary skill in the art, with personal knowledge of the then state-of-art, conclusively demonstrate a long-felt need to solve this technical problem. *Id.* The nexus here cannot be denied – this is the exact same technical problem addressed by the patents.

This evidence also establishes the failure of others to solve this technical problem. *See* Section IV(B). None of the known prior art systems, prior to the Hawk, were capable of field-use for detecting gas leaks under variable ambient conditions. *See id.; see also* Sections IV(D)(2) and (IV)(E)(1-3). This inability of others to solve the problem also has an undeniable nexus to the challenged claims – the problem was not solved because none of the prior art attempted solutions was able to detect a leak under "normal operating conditions" and "variable ambient conditions." These claim elements were added during prosecution specifically to distinguish the prior systems that were unsuitable for use under normal and variable conditions.

The Board further rejected the evidence of long-felt need and failure of others based on its finding that the new EPA alternative work practice permits the use of other types of optical imaging equipment (not solely Furry's passive-IR design). (A43) It is unclear why this one fact would negate the strong evidence of nexus for long-felt need and failure of others, as discussed above. Moreover, the Board's EPA argument ignores the evidence of record establishing that Furry's passive-IR camera, with its particular filter configuration, has in practice become the industry's technical replacement for Method 21. (A16134 ¶¶78-79; A7257-7262; A17632 ¶52)

LSI also presented compelling evidence of copying and commercial success, with an undeniable strong nexus to the novel elements of the patent claims. *See* Section IV(C)(4). The Board ignored the evidence of copying and commercial success based on its finding of a lack of evidence establishing a nexus to the novel elements of the claims. (A44-45) But this finding is not supported by substantial evidence because it ignores FLIR's own internal documents and emails between high-level executives, which establish an undeniable nexus.

FLIR copied Furry's custom filter specifications because Furry overcame "deficiencies in the Merlin" that otherwise made it unsuitable for LDAR. (A22479-80; A22481-85; A23925-40; A23941-46; A23947-50) FLIR's own internal and public admissions establish the nexus. (*Id.*; A22506-7; A22508-11; A22512) The filter configurations of FLIR's GasFindIR remain unchanged to this day. (A23909-24) FLIR's own marketing materials touted the novel filter configuration as a necessary component for permitting leak detection. (A23925-40; A23941-46; A23947-50) FLIR, then under a license agreement with Furry, marked the cameras with David Furry's then-pending patent application number. (A23947-50)

The Board found: "the only feature LSI identifies with a nexus to the claimed invention that is not present in the preexisting Merlin-MID camera is the use of a narrowband cold filter that is described in the marketing material for the GasFindIR camera... . Such objective evidence of nonobviousness cannot overcome the disclosures that narrowband cold filters were disclosed in the prior art, Kulp and Strachan." (A45) This finding is not supported by substantial evidence. As discussed above, ***none*** of the known prior art disclosed, or even suggested, a "narrowband" filter located inside the refrigerated section of the camera. *See* Section VI(E).

Finally, LSI also presented significant evidence of industry accolades and recognition. (A1118-19; A13871-75; A15530-31 ¶¶143-46; A16130-34 ¶¶65,69,72,78; A17061-62 ¶¶28-32; A17620-23 ¶¶23,26; A17628-31 ¶¶43,48). Again, the Board improperly rejected this evidence based upon its erroneous view of the claims and its erroneous claim constructions. (A45)

The Board's failure to give due consideration to this strong evidence of secondary considerations is reversible error. *See, e.g., Nike, Inc. v. Adidas AG,* 2016 U.S. App. LEXIS 2376 at *23-25 (Fed. Cir 2016) (reversing PTAB decision for failing to consider secondary considerations). *See also In re Cyclobenzaprine,* 676 F.3d 1063, 1075-76 (Fed. Cir. 2012); *Crocs, Inc. v. International Trade Commission*, 598 F.3d 1294, 1310 (Fed. Cir. 2010).

G. The Court Should Reverse and Render Judgment for LSI; Remand is Not Appropriate Given the Record of This Case.

For the reasons stated, the Board's FWD is legally erroneous and many of its factual findings are not supported by substantial evidence. The decision must be vacated or reversed.

LSI contends that remand of this case to the PTAB is inappropriate and not required given the factual record below. Where the record on appeal permits the appellate court to reach a final determination on the merits, rendering of judgment without remand is appropriate. *See, e.g. Belden, Inc. v. Berk-Tek, LLC,* 80 F.3d 1064, 1082 (Fed. Cir. 2016) (reversing PTAB judgment in part, and rendering judgment); *In re Bell*, 991 F.2d 781, 785 (Fed. Cir. 1993).

As discussed above, FLIR did not even attempt to offer evidence that the alleged combinations satisfy the claim limitations requiring imaging a gas or detecting a leak under "variable ambient conditions" or "normal operating conditions." *See* Section VI(D). FLIR should not be given another opportunity on remand to offer additional proof. *See* 35 U.S.C. §112; 37 C.F.R. §42.104.

FLIR has had enough chances to submit its proof, having filed five IPR petitions and having submitted four reply declarations after LSI filed its Response.

In addition to the evidentiary hole relating to critical claim elements, FLIR's proof also was littered with sworn testimony that turned out to be false, and that FLIR's witnesses disclaimed under cross-examination. *See* A21731 182:3-21; A3223-A3224 ¶8; A30240 ¶13; A22655-22656 23:22-24:9; A22712-22715 80:23-83:14 (Merlin User Guide was not available on the internet, contrary to sworn testimony); A7943 ¶12; A21705-21706 150:17-151:19 (FLIR customers did not routinely order custom Merlin-MIDs with a custom narrow filter in the cold section); A7956 ¶28; A21826 271:4-271:14 (Richards disclaimed conceiving of cold filtering for the Hawk); (A23037-23043 209:18-215:13) (FLIR witness Woolaway insists that Richards conceived of this idea, despite Richards disclaiming the testimony); A14371-14373 18:16-20:18 (FLIR witness offered to authenticate documents testifies that he has never seen the documents before signing his declaration).

Enough is enough. The record before the Court conclusively establishes that FLIR failed to carry its burden to show that the challenged claims are unpatentable. The Court should reverse the FWD and render judgment in favor of LSI, dismissing FLIR's IPR petitions.

VII. CONCLUSION

For the foregoing reasons, the Board's decision below should be reversed.

Dated: March 9, 2016

Respectfully submitted,

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ADDENDUM

ADDENDUM TABLE OF CONTENTS

Page

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IPR2014-00411 Paper 114
IPR2014-00434 Paper 16
IPR2015-00065 Paper 72
Entered: September 3, 2015

UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

FLIR SYSTEMS, INC.,
Petitioner,

v.

LEAK SURVEYS, INC.,
Patent Owner.

Case IPR2014-00411/434 (Patents 8,426,813 B2 and 8,193,496 B2)
Case IPR2015-00065 (Patent 8,426,813 B2)

Before FRED E. McKELVEY, JAMES T. MOORE, and TREVOR M. JEFFERSON, *Administrative Patent Judges.*

JEFFERSON, *Administrative Patent Judge.*

FINAL WRITTEN DECISION
35 U.S.C. § 318(a) and 37 C.F.R. § 42.73

I. INTRODUCTION

A. Background

FLIR Systems, Inc. ("Petitioner" or "FLIR") filed four petitions seeking *inter partes* review of U.S. Patent No. 8,426,813 B2 ("the '813 patent") and U.S. Patent No. 8,193,496 B2 ("the '496 patent"). Filed were a first petition in IPR2014-00411 ("IPR '411") and a second petition in IPR2014-00608 ("IPR '608") seeking *inter partes* review of claims 1–58 (all of the claims) of the '813 patent. 35 U.S.C. § 311; Paper 2 (IPR '411); Paper 2 (IPR '608).[1] Also filed were a third petition in IPR2014-00434 ("IPR '434") and a fourth petition in IPR2014-00609 ("IPR '609") seeking *inter partes* review of claims 1–7 and 9–20 the '496 patent. 35 U.S.C. § 311; Paper 2 (IPR '434); Paper 2 (IPR '609).

Leak Surveys, Inc. ("Patent Owner" or "LSI") filed a Patent Owner's Preliminary Response in IPR '411 (Paper 6 corrected by Paper 8); IPR '608 (Paper 6 corrected by Paper 8); IPR '434 (Paper 6); and IPR '609 (Paper 7).

In a consolidated Decision to Institute (Paper 9 in IPR '411 and Paper 9 in IPR '434, "Dec. '411"), we denied institution in IPR '608 and IPR '609 and in IPR '411 and IPR '434 instituted this proceeding as to claims 1–22, 31, 37–40, 42–56, and 58 of the '813 patent and claims 1–7 and 9–20 of the '496 patent. Dec. '411, 35–36. Subsequently, we consolidated IPR2014-00434 with IPR2014-00411 and terminated the IPR2014-00434 proceeding. Paper 10 (IPR '411); Paper 9 (IPR '434).

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[1] The IPR in parentheses after a paper number or exhibit number indicates the IPR docket that contains the numbered filing.

In IPR2015-00065 ("IPR '065"), FLIR filed a fifth petition, requesting *inter partes* review of claims 23–30, 32–36, 41, and 57 of the '813 patent pursuant to 35 U.S.C. §§ 311–319. Paper 2 (IPR '065). FLIR subsequently withdrew claim 29 from the requested *inter partes* review, thus challenging only claims 23–28, 30, 32–36, 41, and 57 of the '813 patent. Paper 10 (IPR '065). LSI filed a Preliminary Response in two parts, Part 1 (Paper 8 (IPR '065)) and Part 2 (Paper 16 (IPR '065)).

Pursuant to 35 U.S.C. § 314, in our Decision to Institute (Paper 25, "Dec. '065"), we instituted *inter partes* review as to claims 23–28, 30, 32–36, 41, and 57 of the '813 patent. Dec. '065, 18–19. We further combined IPR2014-00411 with IPR2015-00065 for purposes of scheduling, briefing, and trial. Paper 28, 7 (IPR '065).

LSI filed a Patent Owner Response as to all IPRs (Paper 65 (IPR '411), Paper 37 (IPR '065), "PO Resp.") and FLIR filed a Reply to the Patent Owner Response (Paper 77 (IPR '411), Paper 42 (IPR '065), "Reply").[2] A consolidated oral hearing for IPR2014-00411 and IPR2015-00065 (Paper 70 in IPR '065 and Paper 112 in IPR '411, "Tr.") was held on July 2, 2015.

For the reasons that follow, we determine that FLIR has shown by a preponderance of the evidence that claims 1–28 and 30–58 of the '813 patent and claims 1–7 and 9–20 of the '496 patent, are unpatentable.

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[2] All references herein to the Patent Owner Response (PO Resp.) are to the redacted Paper 66 (IPR '411) and Paper 37 (IPR '065).

B. Related Cases

FLIR states that the ’813 patent, which claims priority to the ’496 patent, has been asserted by LSI in *Leak Surveys, Inc. v. FLIR Systems, Inc.*, Civil Action No. 3:13-CV-02897-L (N.D. Tex.) (filed July 25, 2013). Paper 2, 1 (IPR ’411); Paper 4, 2 (IPR ’065).

C. The Asserted Grounds

In the consolidated IPRs, we instituted trial on the grounds that the following cited references[3] render the challenged claims unpatentable as obvious pursuant to 35 U.S.C. § 103(a):

References	IPR	Claim(s) Challenged
Merlin Brochure[4] and Strachan[5]	IPR ’411	’813 Patent: 1–4, 6, 8–22, 31, 37–40, 42–56, 58
Merlin Brochure, Strachan, and Piety[6]	IPR ’411	’813 Patent: 5 and 7
Merlin Brochure and Strachan	IPR ’434	’496 Patent: 1–5 and 9–20
Merlin Brochure, Strachan, and Brengman[7]	IPR ’434	’496 Patent: 6

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[3] Exhibit numbers herein refer to exhibits filed in both IPR ’411 and IPR ’065 that share the same number. An exhibit number followed by a specific IPR in parentheses denotes an exhibit filed in the identified IPR.

[4] Indigo Systems Corporation, Merlin: The ultimate combination of flexibility and value in high-performance Infrared Cameras (Rev. A 1/02), dated ©2002 (Ex. 1007, “Merlin Brochure”).

[5] D.C. Strachan et al., *Imaging of Hydrocarbon Vapours and Gases by Infrared Thermography*, 18 J. PHYS. E: SCI. INSTRUM. 492-498 (1995) (Ex. 1008, “Strachan”).

[6] U.S. Patent No. 5,386,117 issued on January 31, 1995 (Ex. 1018, “Piety”).

References	IPR	Claim(s) Challenged
Merlin Brochure, Strachan, and Hart[8]	IPR ’434	’496 Patent: 7
Merlin Brochure and Strachan	IPR ’065	’813 Patent: 23, 25, 28, 30
Merlin Brochure, Strachan, and Spectrogon[9]	IPR ’065	’813 Patent: 27, 32–35, 41
Merlin Brochure, Strachan, and OCLI[10]	IPR ’065	’813 Patent: 24, 26, 36, 57
Merlin User’s Guide[11] and Kulp[12]	IPR ’065	’813 Patent: 23, 33, 35
Merlin User’s Guide, Kulp, and Spectrogon	IPR ’065	’813 Patent: 25, 27, 28, 30, 32, 34, 41
Merlin User’s Guide, Kulp, and OCLI	IPR ’065	’813 Patent: 24, 26, 36, 57

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[7] U.S. Patent No. 3,662,171 issued on May 9, 1972 (Ex. 1013 (IPR ’434), “Brengman”).

[8] U.S. Patent No. 6,056,449 issued on May 2, 2000 (Ex. 1014 (IPR ’434), “Hart”).

[9] Spectrogon Catalog of Bandpass Filters (http://www.spectrogon.com /bandpass.html dated October 6, 2001) (Ex. 1017, “Spectrogon”).

[10] OPTICAL COATING LABORATORY, INC. SPECTRABAND STOCK PRODUCTS CATALOG, Vol. 5 (1994) (Ex. 1014, “OCLI”).

[11] Indigo Systems Corporation, MERLIN™ MID, INSB MWIR CAMERA, User’s Guide, Version 1.10, 414-0001-10 (Ex. 1011, “Merlin User’s Guide”).

[12] Thomas J. Kulp et al., *Remote Imaging of Controlled Gas Release using Active and Passive Infrared Imaging Systems*, 3061 SPIE 269 (1997) (Ex. 1012, “Kulp”).

D. The '813 Patent and Illustrative Claims

The '813 patent is based on an application which is a continuation of the application that matured into the '496 patent. Ex. 1001, 1:6–9.[13] The '813 patent relates to an infrared (IR) camera system which can be used to visually detect and identify chemical, gas, and petroleum product leaks. Ex. 1001, 1:27–29, 28:44–67.

The '813 invention is readily understood by reference to its drawings and exemplary claims 1, 23, and 24. Figs. 1 and 2 of the '813 patent are reproduced below.

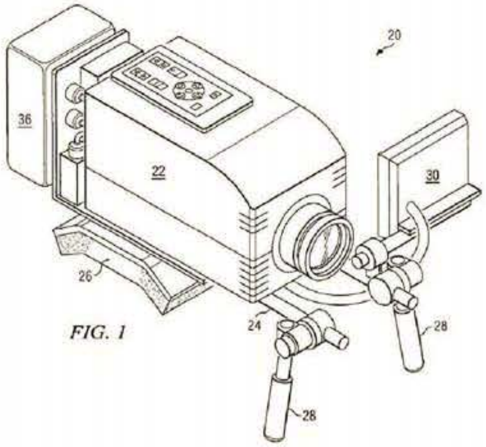

FIG. 1

Fig. 1 depicts a perspective view of a chemical leak detection system

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[13] Ex. 1001 refers to the '813 patent filed in both IPR '411 and IPR '065.

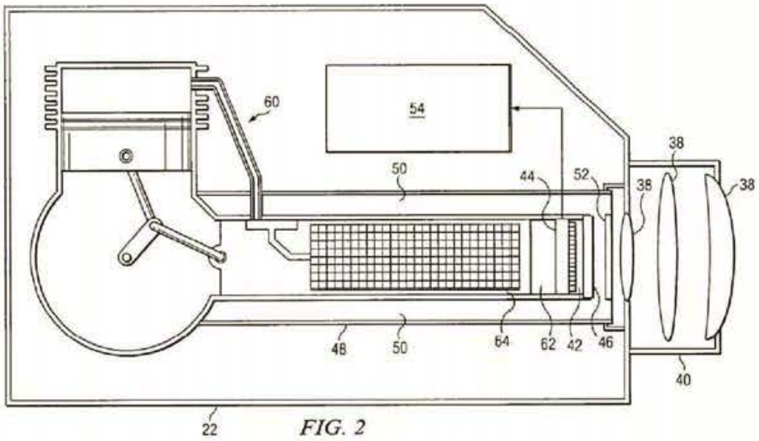

FIG. 2

Fig. 2 depicts a schematic of an infrared camera system of Fig. 1

Figures 1 and 2 show infrared camera system 22, lens assembly 40, and lens 38. Ex. 1001, 5:34–38. Camera system 22 has refrigerated portion 42 cooled by refrigeration system 60. *Id.* at 5:34–41, 5:66–67. The refrigerated portion 42 also comprises infrared sensor device 44 and optical bandpass filter 46. *Id.* at 5:41–43. The refrigeration cools optical bandpass filter 46, reducing the background noise of bandpass filter 46 as perceived by infrared sensor device 44. *Id.* at 6:45–47. Optical bandpass filter 46 is located along an optical path between lens 38 and infrared sensor device 44. *Id.* at 5:41–43. At least part of a pass band for optical bandpass filter 46 is within an absorption band for the detected chemical. The infrared image of the detected chemical passes through the lens and optical bandpass filter and the filtered infrared image of the leak is received with the infrared sensor device. *Id.* at 3:4–11. The visible image of the leak is produced by processing the filtered infrared image received by the infrared sensor device. *Id.*

Independent claim 1 and dependent claims 23 and 24 are illustrative of the claimed subject matter of the ’813 patent.

> 1. A system for producing a visible image of a leak of any one or more chemicals of a group of chemicals, the leak emanating from a component, including:
>
> a passive infrared camera system including:
>
> a lens assembly including a lens;
>
> a refrigerated portion including an interior;
>
> an infrared sensor device located in the interior of the refrigerated portion;
>
> a single filter configuration located in the interior of the refrigerated portion and including an optical bandpass filter fixed along an optical path between the lens assembly and the infrared sensor device;
>
> a refrigeration system that can cool the interior of the refrigerated portion;
>
> wherein at least part of the pass band for the single filter configuration is within an absorption band for each of the chemicals; and
>
> wherein the aggregate pass band for the single filter configuration is at least about 100 nm; and
>
> a processor that can process a signal representing the filtered infrared image captured by the infrared sensor device to produce a visible image of the chemical emanating from the component under variable ambient conditions of the area around the leak.
>
> 23. The system of claim 1, wherein the aggregate pass band for the single filter configuration is at least about 200 nm.
>
> 24. The system of claim 1, wherein the pass band for the filter configuration has a center wavelength located between about 3375 nm and about 3385 nm.

Ex. 1001, 28:44–67, 30:3–7.

E. The '496 Patent and Illustrative Claim

The '496 patent relates to a method of using an IR camera system to visually detect and identify chemical, gas, and petroleum product leaks. Ex. 1001, 1:25–27, 28:41–29:8.[14] The drawings and written description portion of the Specification of the '496 patent are essentially the same as the drawings and written description portion of the Specification of the '813 patent. *Compare* Ex. 1001 (IPR '434) *with* Ex. 1001.

Claim 1 is illustrative of the subject matter of the '496 patent.

> 1. A method of visually detecting a gas leak of any one or more chemicals of a group of predetermined chemicals, the gas leak emanating from a component of a group of components in different locations, the method comprising:
>
> aiming a passive infrared camera system towards the component, wherein the passive infrared camera system comprises:
>
> a lens,
>
> a refrigerated portion defined by the interior of a Dewar flask, the refrigerated portion comprising therein:
>
> an infrared sensor device; and
>
> a single filter configuration comprising at least one fixed optical bandpass filter, each filter fixed along an optical path between the lens and the infrared sensor device, wherein at least part of the aggregate pass band for the single filter configuration is within an absorption band for each of the predetermined chemicals and

---

[14] Ex. 1001 (IPR '434) refers to the '496 patent filed in IPR '434.

> wherein the aggregate pass band for the single filter configuration is at least about 200 nm; and
>
> a refrigeration system adapted to cool the refrigerated portion, the refrigeration system comprising a closed-cycle Stirling cryocooler;
>
> filtering an infrared image associated with the area of the gas leak under normal operating and ambient conditions for the component with the at least one optical bandpass filter;
>
> receiving the filtered infrared image of the gas leak with the infrared sensor device;
>
> electronically processing the filtered infrared image received by the infrared sensor device to provide a visible image of the gas leak under variable ambient conditions of the area around the leak; and
>
> visually detecting the leak based on the visible image under the variable ambient conditions.

Ex. 1001 (IPR '434), 28:40–29:8.

II. ANALYSIS

A. Claim Construction

The Board interprets claims of an unexpired patent using the broadest reasonable construction in light of the specification of the patent in which they appear. *See* 37 C.F.R. § 42.100(b); *In re Cuozzo Speed Techs., LLC*, 793 F.3d 1268, 1278–79 (Fed. Cir. 2015). Claim terms generally are given their ordinary and customary meaning, as would be understood by one of ordinary skill in the art in the context of the entire disclosure. *See In re Translogic Tech., Inc.*, 504 F.3d 1249, 1257 (Fed. Cir. 2007).

1. "leak"

In the preliminary Decision to Institute, we found that "leak" is broad enough to include both fugitive and non-fugitive emissions. Dec. '411, 17. Thus, on the preliminary record we agreed with FLIR that "leak" should be defined as any chemical emission including (1) an unwanted ("fugitive") chemical emission and (2) a known ("non-fugitive") chemical emission, such as a chemical gas emission from an exhaust outlet of an airplane or a smokestack. Paper 2, 12 (IPR '411); Paper 2, 10 (IPR '434); Paper 2, 12–13 (IPR '065). We found that the '813 patent states that "[a]n embodiment of the present invention may be used to inspect any of a wide variety of components having [a] chemical . . . of interest . . . , including (but not limited to) a pipe, a compressor, . . . a flare, an exhaust outlet, . . . [or] a vent for a blow-off valve." Ex. 1001, 12:17–25.

LSI disagrees with our preliminary construction and argues that the construction of "leak" deviates from the ordinary meaning of the term. PO Resp. 31–33. LSI relies on extrinsic evidence to supports its contention that the ordinary meaning of "leak" as recited in the '813 and '496 patents is limited to unintended or fugitive emissions. PO Resp. 33. LSI's contention fails to recognize and distinguish the express teaching that chemicals of interest from flares, exhausts, vents or blow off valves are expressly described as uses of the claimed invention. Ex. 1001, 12:17–25. Indeed, one portion of the specification that LSI relies on to distinguish known versus unknown emissions, indicates that the invention is used to survey known emissions of gas from vents. Ex. 1001, 20:28–31; *see* PO Resp. 34.

Although LSI admits that exhaust valves and flares will have known emissions and that the invention is used to survey these structures (PO Resp.

32), LSI argues that the term "leak" does not include the known emissions from these structures, as the ordinary use of the term is limited to fugitive or unknown emissions. We disagree, concluding that a person of ordinary skill in the art would understand that the specification describes a chemical of interest that is present in valves and exhausts that have known emissions. Ex. 1001, 12:22, 20:28–32.[15]

Under the broadest reasonable interpretation, LSI's extrinsic evidence does not persuade us that a person of ordinary skill in the art would understand that "leak" as used in the specification and claims is limited to only unknown or fugitive emissions. Accordingly, on the full record, we maintain our construction of "leak" as including both fugitive and non-fugitive emissions.

2. *"produce a visible image of the chemical emanating from the component under variable ambient conditions of the area around the leak"*

In the Decision to Institute, we preliminarily construed "produce a visible image of the chemical emanating from the component under variable ambient conditions of the area around the leak" means "being able to produce a visible image under the ambient conditions of the area around the

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[15] In addition, we note that LSI's claims using the term "leak" were rejected over intended or known emissions from a smokestack. *See* Ex. 1002, 319, 416–419. Patent Owner disputed and overcame the Examiner's rejection on different grounds, but did not dispute the Examiner's application of smokestack emissions to gas leaks. *See id.* Thus, at least during prosecution, the term leak was determined by the Examiner to include known emissions.

leak." Dec. '411, 17–18. LSI does not dispute this construction, but instead argues that

> POSITA [i.e., a person having ordinary skill in the art,] would understand this claim limitation to require that the claimed invention be capable of operating under a full range of normal operating conditions, such as different temperatures or sunlight; and it would not encompass prior art systems that could image gases only within a narrow range of field conditions, such as temperature.

PO Resp. 27. Specifically, LSI argues that "in the context of the full claims, this limitation should be construed to mean that an infringing method must operate to image gas leaks under real-world field conditions, without taking steps to artificially control any variables such as background temperature, wind, etc." *Id*. at 25. LSI does not provide any argument or evidence that the patent describes the range of "real-world" versus "artificially controlled" conditions. Instead, LSI's construction merely seeks to eliminate any conditions obtained in a lab or test setting from ambient conditions in other settings.

We are not persuaded that the patent claims' references to variable ambient conditions are limited to "real-world" conditions. As we previously noted, a person having ordinary skill in the art would understand that the claimed system and method would typically be used outdoors, where environmental conditions change, at the point where a leak may occur. Dec. '411, 18. For example, in the summer, a chemical of interest may be present at higher temperature than the same chemical of interest in the winter. *Id.* Similarly, exhaust temperature may vary depending on conditions.

LSI admits that "the claim does not specify what the normal operating conditions would be" under given circumstances. Oral Argument Transcript ("Tr.") 62:23–24. LSI also admits that a smokestack, for example, would have "a different range of normal operating conditions." Tr. 63:6–8. Because these conditions vary and the '813 and '496 patent specifications are silent on the range or limits of normal operating conditions, we are not persuaded by LSI's attempt to exclude controlled environments from the claimed ambient conditions. *See* PO Resp. 26–27. We find no support for LSI's contention that "variable ambient conditions" or "normal operating in variable ambient conditions" is limited to those instances that are not constrained or controlled in some artificial manner. *Id.*

On the full record, we maintain our constructions of "produce a visible image of the chemical emanating from the component under variable ambient conditions of the area around the leak" as meaning "being able to produce a visible image under the ambient conditions of the area around the leak."

B. Asserted Prior Art

1. Merlin Brochure (Ex. 1007)

The Merlin Brochure discloses a mid-wavelength (MWIR) infrared camera ("Merlin-MID") that includes an infrared sensor device (InSb focal plane array) and a 3-5 µm bandpass cold filter within a refrigeration portion defined by the interior of a Dewar flask. Ex. 1007, 3, 6; *see* Ex. 1011, 1. The Merlin-MID also includes a refrigeration system (a closed-cycle Stirling cryocooler) that cools the refrigeration portion of the Merlin-MID and the filter. Ex. 1007, 6.

The ’813 patent states that “[a] preferred infrared camera system 22, for example, for use in an embodiment of the present invention is a Merlin™ mid-wavelength infrared (MWIR) high-performance camera available from Indigo Systems, Inc. in California.” Ex. 1001, 6:19–23. The Merlin-MID camera described in the brochure is the Merlin MWIR camera discussed in the ’813 patent. Ex. 1001, at [56] (citing Merlin Brochure by Indigo Systems Corp. (2002)), 6:19–23 (citing Merlin mid-wavelength infrared MWIR camera as the preferred embodiment of camera system 22).

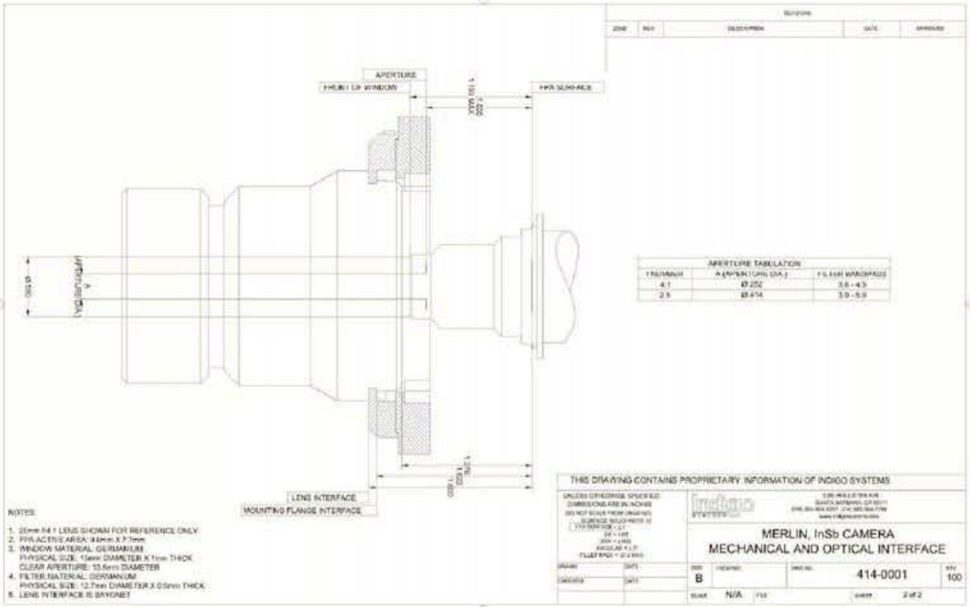
2. *Merlin User’s Guide (Ex. 1011)*

The Merlin User’s Guide describes features of the Merlin Brochure MID InSb camera. The Merlin User’s Guide discloses a passive infrared camera with a refrigeration portion including an interior. Ex. 1011, 2, 51. Merlin User’s Guide describes both a cold filter and infrared sensor device located in the interior of the refrigeration portion. *Id.* at 51.

The Merlin User’s Guide states:

> Merlin Mid is a mid-wavelength infrared (MWIR) high-performance camera offered by Indigo systems Corp. The camera consists of a Stirling-cooled Indium Antimonide (InSb) Focal Plane Array (FPA) built on an Indigo Systems ISC9705 Readout Integrated Circuit (ROIC) using indium bump technology. The FPA is a 320 x 256 matrix or ‘staring’ array of detectors that are sensitive in the 1.0 μm to 5.4 μm range. The standard camera configuration incorporates a cold filter that restricts the camera’s spectral response to the 3.0-5.0 micron band. The FPA is enclosed in an all-metal evacuated [D]ewar assembly cooled by a closed-cycle Stirling cryocooler, and is thermally stabilized at a temperature of 77 K.

Ex. 1011, 1. "The lens-to-camera interface is shown in Appendix B" (Ex. 1011, 3) reproduced below.



Depicted above is the Merlin InSb camera, mechanical and optical interface.

The filter is located in the general area of the "aperture" and the filter bandpass is identified as 3.6 to 4.9 or 3.0 to 5.0 depending on the aperture diameter. Ex. 1101, 51. The IR sensor is located in the general area identified as FPA (focal point array) sensor. The refrigerated area is the space between the filter and the IR sensor.

3. Kulp (Ex. 1012)

Kulp discloses "results of field tests of an active backscatter absorption gas imaging (BAGI) system and a passive imager on a Ga:Si infrared focal-plane array." Ex. 1012, 269 (Abstract). The passive imager on an infrared focal-plane array "images gases through temperature or emissivity differences." *Id.*

Specifically, Kulp discloses a camera equipped with a narrow bandpass cold filter to detect sulfur hexafluoride (SF6) gas. Ex. 1012, 270. Figure 2 of Kulp shows that the cold filter has an aggregate passband of about 570 nm between wavenumber 920 (about 10870 nm) and wavenumber 970 (about 10300 nm). *Id.* at 270 (Figure 2). In addition, Figure 9 of Kulp shows that the Ga:Si passive infrared camera provides a visible image of the SF6 gas at different times of day at different temperatures. *Id.* at 277. Figure 9 is depicted below.

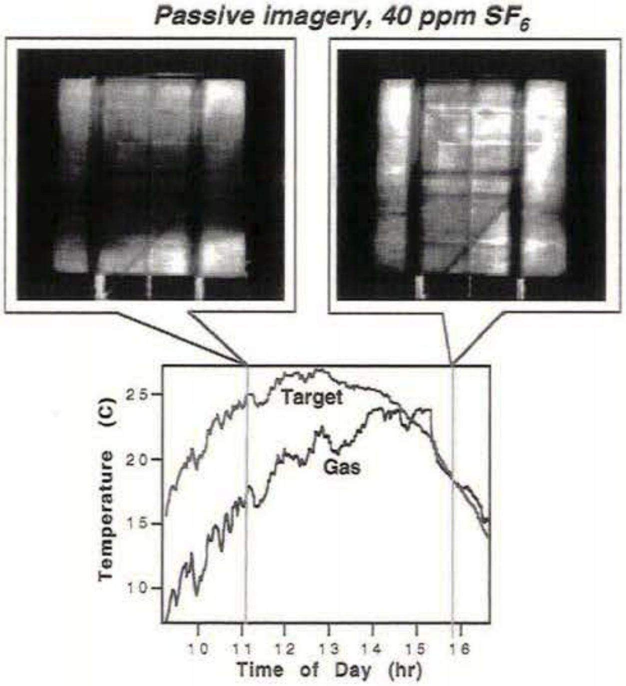


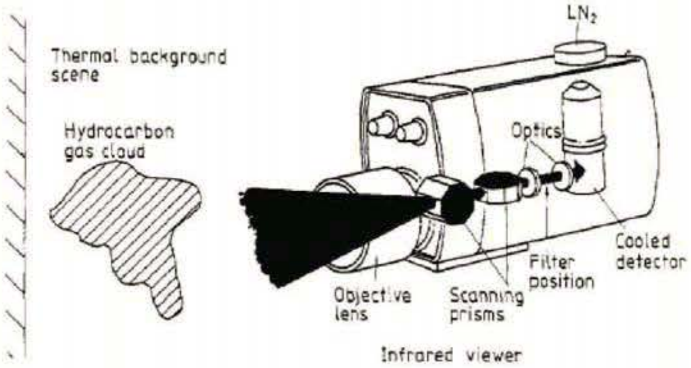
Figure 9 shows passive images collected of gas releases at two different times of the day. The graph plots the target and air temperature during the day. *Id.* Kulp states that "[the passive IR approaches] are attractive because of its unlimited range and spectral bandwidth, and its simplicity . . . . Its use must, however, be accompanied by the assumption that the required temperature and/or emissivity differences between the gas and background will always exist." Ex. 1012, 277.

4. Strachan (Ex. 1008)

Strachan discloses a demonstration of "an infrared imaging technique for the visualization of hydrocarbon gases and vapours." Ex. 1008, 1 (Abstract). Strachan describes "a qualitative imaging approach to gas/vapour detection." *Id.* at 1 (Section 1). Strachan states:

> The technique is based on real-time infrared imaging (thermography), which produces images of objects from their own infrared heat radiation. By selecting spectral absorption windows characteristic of hydrocarbon vapours and gases it is possible to visualise such gases against a background thermal scene. The approach and its limitations in terms of hydrocarbon detection and instrument development requirements for ambient temperature operations are discussed.

Id. Figure 3 shows the schematic of a hydrocarbon imaging system disclosed in Strachan.



"Figure 3 indicates schematically the operation of a hydrocarbon detection system." Ex. 1008, 493. Figure 3 shows "a detector is housed in its own Dewar flask, which contains a small quantity of liquid nitrogen coolant.

Infrared radiation from the source object is imaged by a multi-element lens, generally silicon or germanium." Ex. 1008, 493. Strachan states:

> The detector signal is then processed electronically to produce a real-time infrared television picture or thermogram. . . . . The camera views the thermal background scene around and through any intervening hydrocarbon cloud. Providing background and cloud are not in total thermal equilibrium with each other, then it is possible to visualise the gas cloud against the background.

Id. Strachan disclosed an infrared imaging system fitted with a specific filter for detecting hydrocarbon gases, discussing two different example filters, having bandwidths centered approximately at 3.4 μm, for detecting hydrocarbon gases. *Id.* Furthermore, Strachan discloses the use catalogs of infrared absorption spectra for various hydrocarbon vapors. *Id.*

5. Hart (Ex. 1014 (IPR '434)

Hart is a U.S. patent, issued on May 2, 2000, titled "Frame Assembly For Supporting A Camera." Figure 1 of Hart is reproduced below.

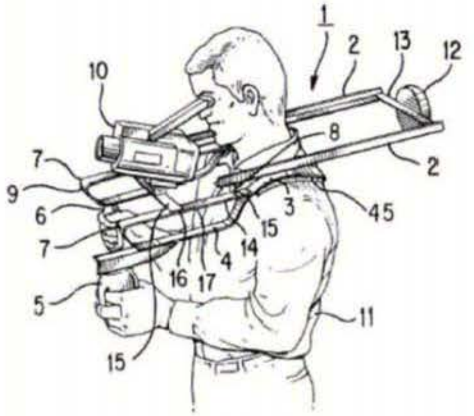


FIG. 1

Figure 1 of Hart shows a camera supported by a frame assembly that includes frame 4, 7, shoulder rest 3, and handle 5, 6 extending from the frame. Ex. 1014 (IPR ’434), 4:41–45, 52–55, 5:24–25. Figure 1 of Hart also discloses that aiming the camera towards a component is performed by a person holding the infrared camera system.

6. Spectrogon (Ex. 1017) and OCLI (Ex. 1014)

Spectrogon shows a catalog of bandpass filters available at the time of the invention. Ex. 1017. The Optical Coating Laboratory, Inc. (“OCLI”) products catalog likewise discloses a catalog of optical filters available at the time of invention. Ex. 1014.

7. Piety (Ex. 1018)

Piety is a U.S. patent issued in 1995, titled “Infrared Thermography System Including Mobile Unit,” and discloses a mobile infrared thermography unit that includes a data processing device operable to record user notes. Ex. 1018, 14: 18-22. Specifically, Piety discloses:

> The mobile infrared thermography unit includes an infrared camera, a storage device such as a videotape recorder for at least recording thermographic images captured by the infrared camera, and a mobile unit computer. The mobile unit computer includes a touch screen display for presenting information to a thermographer and for receiving data and command inputs from the thermographer.

Ex. 1018, Abstract ll. 4–11.

8. Brengman (Ex. 1013 (IPR '434))

Brengman is a U.S. patent that issued in 1972, titled "Methane Gas Detection System Using Infrared." Brengman discloses using an infrared gas detection system mounted on an airborne platform to detect methane gas leaks in buried gas pipelines. Ex. 1013 (IPR '434), 1:70–72, 4:12–15. Brengman further discloses that the airborne platform may be a helicopter. *Id*. at 7:38–40.

C. Merlin References as Prior Art and Printed Publication

FLIR contends that the Merlin Brochure (Ex. 1007) is a prior art printed publication. Paper 2, 10 (IPR '65); Paper 2, 8–9 (IPR '411). At the time of filing the Response, LSI contested whether the Merlin Brochure is publicly available prior art. PO Resp. 70–73. At oral argument, LSI withdrew its argument that the Merlin Brochure was not publicly available. Tr. 40:1–9 (stating that LSI no longer contends that the Merlin Brochure was not publicly available).

With respect to the Merlin User's Guide (Ex. 1011), FLIR argues that testimony evidence shows that the guide was distributed with sales of the Merlin camera. Ex. 1016 ¶ 7 (stating that "[t]he Merlin User's Guide is a user guide that describes the Merlin-MID camera sold by Indigo" and "distributed to customers with the Merlin-MID camera").

LSI argues that because the Merlin User's Guide was only delivered to purchasers of the expensive Merlin MID camera (citing Ex. 2063 at LSI0000483, LSI0000816, LSI0000853), it was not available such that ordinarily skilled artisans could locate it by exercising reasonable diligence. *See In re Klopfenstein*, 380 F.3d 1345, 1350 (Fed. Cir. 2004). LSI further argues that publications that are available only at high costs render the document effectively inaccessible to members of the general public. PO Resp. 70 (citing *Virginia Innovation Scis., Inc. v. Samsung Elecs. Co.*, 983 F. Supp. 2d 713, 738 (E.D. Va. 2014)). We note that LSI acknowledges that a Merlin user's guide with the same title as the Merlin User's Guide (Ex. 1011) was previously considered during prosecution. PO Resp. 73. LSI also acknowledges that FLIR's witnesses state the Merlin User's Guide (Ex. 1011) was available to purchasers of the Merlin MID as of the critical date. PO Resp. 71. Despite this evidence of public availability, LSI argues that the guide was only available to purchasers of the camera and the expense of buying the camera means the Merlin User's Guide (Ex. 1011) is not a printed publication freely accessible to the public prior to the critical date. PO Resp. 71 (citing *Virginia Innovation*. 983 F. Supp. 2d at 738).

We are not persuaded by LSI's arguments. The case LSI relies on, *Virginia Innovation*, is neither binding authority nor persuasive authority. The facts in *Virginia Innovation* can be distinguished from the facts of the present case, as the prior art in question in *Virginia Innovation* was not sufficiently shown to be generally on sale to the interested public, and was instead "restricted" to members of a publishing organization, which required membership dues for access. *See* 983 F. Supp. 2d at 737–38. Indeed, the district court in *Virginia Innovation* noted that there was no evidence that the document was available for sale to the general public outside of the publishing organization members. *Id.* In the present case, no membership fee or organization membership is required for access to the Merlin User's Guide, which testimony shows was available and sold to the interested public as early as late 2000. *See* Ex. 1026 ¶¶ 17–19; Ex. 1024 ¶¶ 12–14; Ex. 1016 ¶ 12.

Based on the complete record, we find by a preponderance of the evidence that distribution of the Merlin User's Guide with the sale of the Merlin MID camera shows sufficient public accessibility and distribution. The cost to obtain the camera does not negate the evidence that the camera and accompanying user's guide was available to the interested public. The testimony evidence shows that the Merlin User's Guide was available for sale and distribution to the interested as early as 2000. Thus, FLIR has shown by a preponderance of the evidence that the Merlin User's Guide was a publicly available printed publication.

D. Level of Ordinary Skill in the Art

FLIR contends that a person of ordinary skill in the art would have relevant experience with passive IR (infrared) systems in addition to the requisite engineering or physics education. Paper 2, 10–11 (IPR '065); Reply 19–20. LSI contends that in addition to the requisite physics or optical science/engineering education a person of ordinary skill the art would have experience developing IR camera systems generally. PO Resp. 22. LSI's contention is that FLIR's definition of a person of ordinary skill is too narrowly focused on passive IR systems and is evidence of hindsight bias. PO Resp. 23.

LSI's arguments are contradictory and confusing; asserting not only that FLIR's person of ordinary skill in art is overly narrow and defined as a "specialist in the ['813 and '496 patents'] specific solution to the problem being solved," but also that FLIR's artisan "would not [] have been familiar with the technical problem being addressed by the invention." PO Resp. 22 (emphasis omitted). Regardless, FLIR argues that the invention would have been obvious under either FLIR's or LSI's proposed person of ordinary skill in the art. Reply 20.

Based on the full record, we find that the level of ordinary skill in the art is evidenced by the prior art references and the type of problems and solutions described in the '813 and '496 patents (Ex. 1001, 1:25–2:34), and includes experience in imaging of chemical gases using IR camera systems generally in addition to the requisite engineering, physics or optical science education. *See In re GPAC Inc.*, 57 F.3d 1573, 1579 (Fed. Cir. 1995). Moreover, and apart from any differences of opinion between FLIR and LSI on the precise background and knowledge of one skilled in the art, the prior art itself is highly indicative of the level of skill. *See id.* ("the level of ordinary skill in the art . . . was best determined by appeal to the references of record"). In any event, we do not find that a person of ordinary skill's understanding of the teachings of the prior art would differ if an ordinarily skilled artisan possessed knowledge of both active and passive IR systems rather than knowledge of passive IR systems alone. *See* PO Resp. 22–24.

E. Obviousness of the Challenged Claims

FLIR contends that the combinations of the Merlin Brochure, the Merlin User's Guide, Kulp, Strachan, Piety, Spectrogon, and OCLI render claims 1–28 and 30–58 of the '813 patent unpatentable based on obviousness. For the reasons given below, after consideration of the Petition, the arguments in the Patent Owner Response, and the evidence of record, we conclude that FLIR has shown by a preponderance of the evidence that each of claims 1–28 and 30–58 of the ’813 patent is unpatentable as obvious.

FLIR also contends that the Merlin Brochure and Strachan render claims 1–5 and 9–20 of the ’496 patent unpatentable as obvious. Paper 2, 14–48 (IPR ’434). FLIR asserts that dependent claim 6, which depends from claim 1, is rendered unpatentable as obvious by Brengman, the Merlin Brochure and Strachan. *Id.* at 48–50. Finally, FLIR contends that dependent claim 7, which depends from claim 1, is rendered unpatentable as obvious by Hart, the Merlin Brochure, and Strachan. *Id.* at 50–51.

For the reasons that follow, we find by a preponderance of the evidence that FLIR has demonstrated that the challenged claims, claims 1–28 and 30–58 of the ’813 patent and claims 1–7 and 9–20 of the ’496 patent, are unpatentable as obvious.

1. Petitioner’s ’813 Patent Contentions

FLIR asserts that claims 1–4, 6, 8–22, 31, 37–40, 42–56, and 58 are unpatentable under 35 U.S.C. § 103(a) over the Merlin Brochure (Ex. 1007) and Strachan (Ex. 1008). Paper 2, 9, 34 (IPR ’411). FLIR also asserts dependent claims 5 and 7, which depend from claim 1, are unpatentable under 35 U.S.C. § 103(a) over the Merlin Brochure (Ex. 1007), Strachan (Ex. 1008), and Piety (Ex. 1018). Paper 2, 9, 54 (IPR ’411).

FLIR provides claim charts and citations to the Declaration testimony of Dr. Jonas Sandsten (Ex. 1006) supporting its contention that it would have been obvious to combine the Merlin Brochure and Strachan to yield the camera of the claims. *Id.* at 34–40, 41–53. FLIR asserts that “[i]t would have been an obvious design choice to one skilled in the art to replace the standard 3-5 μm filter [disclosed in the Merlin Brochure] with a narrower filter that covers hydrocarbon gases of interest" disclosed in Strachan as a combination of known elements that yield predictable results. *Id.* at 34.

FLIR argues that the claimed camera is nothing more than the result of equipping Petitioner's own Merlin-MID camera disclosed in the Merlin Brochure with a custom filter selected to monitor gas as disclosed in Strachan. Paper 2, 34 (IPR '411). For example, FLIR contends that the Merlin Brochure discloses a passive infrared camera that includes a refrigeration system (a closed-cycle Stirling cryocooler) that contains a standard 3-5 μm cold filter within the interior of a Dewar flask, and an infrared sensor device (InSb focal plane array). *Id.* at 35. FLIR contends Strachan's disclosure of the absorption band for multiple hydrocarbon gases and the selection of an appropriate filter to detect multiple gases, discloses the "the pass band for the single filter configuration" limitation of claim 1. *Id.* at 42–43. Indeed, FLIR further asserts that Strachan discloses that it was known to use catalogs of infrared absorption spectra for gases to select filters for use in an infrared camera with a narrow bandpass filter to monitor and detect hydrocarbon gas and vapor. *Id.* at 36; *see* Ex. 1008, 492–493. FLIR argues that

> Strachan shows that at the time of the alleged invention, it was known in the art to select a filter that covers the absorption band of more than one gas of interest and to use the selected filter in a passive infrared camera to detect leaks of the gases of interest.

Paper 2, 37 (IPR '411); Ex. 1006 ¶ 80.

With respect to independent claim 1 of the '813 patent, FLIR shows that the Merlin Brochure discloses a camera for detecting gas, wherein the

Merlin Brochure discloses "a single filter configuration" in the bandpass filter (cold filter) that is less than 200 nm. Paper 2, 20–31 (IPR '411)(citing Ex. 1007, 3). FLIR further alleges that Strachan discloses the absorption of various hydrocarbon gases and the selection of filters for such detection. Paper 2, 37 (IPR '411) (citing Ex. 1008, 493). In addition, FLIR asserts that the Merlin Brochure and Strachan disclose producing visual images of gas detected at various ambient conditions and temperatures. Paper 2, 40 (IPR '411) (citing Ex. 1006 ¶ 74; Ex. 1008, 492; Ex. 1007, 3).

In IPR '065, FLIR asserts that claims 23, 25, 28, and 30, which depend from independent claim 1, are unpatentable as obvious over the Merlin Brochure (Ex. 1007) and Strachan (Ex. 1008). Paper 2, 17–26 (claim 1), 26–28 (claims 23, 25, 28, and 30). In support of its contentions, FLIR provides claim charts and citations to Dr. Sandsten's testimony (Ex. 1006). *Id.*

FLIR also contends that claims 23, 33, and 35, which depend from independent claim 1, are unpatentable as obvious in view of Kulp (Ex. 1012) and Merlin User's Guide (Ex. 1011). Paper 2, 41–48 (IPR '065). FLIR provides claim charts and citations to the testimony of Dr. Sandsten (Ex. 1006) in support of its contentions. *Id.* FLIR argues that Kulp discloses all the limitations of claim 1, expressly or inherently, except for the "refrigeration portion" limitation of claim 1. Paper 2, 41–43(IPR '065). With respect to refrigeration, FLIR argues that it would have been obvious to locate the cooled filters and array disclosed in Kulp within the refrigeration portion disclosed in the Merlin User's Guide as it represents an obvious design choice. Paper 2, 43–44 (IPR '065) (citing Ex. 1006 ¶¶ 98–100).

FLIR provides claim charts, citations to the testimony of Dr. Sandsten and analysis in support of its contentions that (1) claims 27, 32–35, and 41 are unpatentable as obvious in view of Merlin Brochure, Strachan, and Spectrogon (Paper 2, 28–37 (IPR '065)); and (2) claims 24, 26, 36, and 57 are unpatentable as obvious in view of Merlin Brochure, Strachan, and OCLI (Paper 2, 38–41 (IPR '065)). FLIR relies on the filter characteristics disclosed in Spectrogon and OCLI for "the pass band for the filter configuration" limitations of dependent claims 24, 26, and 27.

With respect to Kulp (Ex. 1012) and the Merlin User's Guide (Ex. 1011), FLIR provides claim charts, analysis and citations to the testimony of Dr. Sandsten in support of its contentions that Kulp and the Merlin User's Guide render dependent claims 23, 33, and 35 (which depend from claim 1) unpatentable as obvious. Paper 2, 41–48 (IPR '065). FLIR asserts the Kulp discloses every limitation of claims 1, 23, 33, and 35, except for the limitations for "an infrared sensor device located in the interior of the refrigerated portion" and "a single filter configuration located in the interior of the refrigerated portion" as recited in claim 1. *Id*. at 44–47. FLIR argues that

> it would have been obvious, in view of the Merlin User's Guide, to modify the camera of Kulp, which already discloses a cooled filter and a cooled infrared sensor device, to locate both the cooled filter and cooled infrared sensor device in the interior of a refrigeration portion, as disclosed in the Merlin User's Guide.

Id. at 44; Ex. 1006 ¶¶ 99–100.

With respect to "the pass band for the filter configuration" limitations of dependent claims 25, 27, 28, 30, 32, 34, and 41, which depend from claim

1, FLIR provides citations to Spectrogon to disclose the filter characteristics, in combination with the Kulp and the Merlin User's Guide to disclose the limitations of independent claim 1. Paper 2, 48–52 (IPR '065). Similarly, FLIR provides citations to OCLI in combination with Kulp and the Merlin User's Guide to disclose "the pass band for the filter configuration" and "optical bandpass filter" limitations of dependent claims 24, 26, 36, and 57. *Id*. at 53–54.

2. *Petitioner's '496 Patent Contentions*

FLIR also contends that the Merlin Brochure and Strachan render claims 1–5 and 9–20 of the '496 patent obvious. Paper 2, 14–48 (IPR '434). FLIR provides claim charts, analysis and citations to the testimony of Dr. Sandsten in supports of its contentions that independent claim 1, 18, 19, and 20 are unpatentable as obvious in view of the Merlin Brochure and Strachan. *Id*. at 14–47.

FLIR asserts that dependent claim 6, which depends from claim 1, is rendered unpatentable as obvious by Brengman, the Merlin Brochure and Strachan. *Id*. at 48–50. Finally, FLIR contends that dependent claim 7, which depends from claim 1, is rendered unpatentable as obvious by Hart, the Merlin Brochure and Strachan. *Id*. at 50–51. In support of its contentions, FLIR provides claim charts and citations to the testimony of Dr. Standsten showing that the combination of the Merlin Brochure and Strachan with Hart or Brengman discloses the limitations of dependent claims 6 and 7. *Id*. at 48–51.

3. *Patent Owner Contentions*

LSI contends that FLIR has not met its burden because none of the asserted prior art teaches a system for detecting or visualizing gas leaks under (1) "variable ambient conditions" as recited in the challenged independent claims or (2) using a "single filter configuration located in the interior of the refrigerated portion" as recited in the challenged claims. PO Resp. 1–2. LSI also argues that FLIR fails to articulate a fact-based rational underpinning for a person of ordinary skill in the art to combine the references. *Id*. at 2. Instead, LSI argues that the prior art teaches away from use of passive-IR to detect gas leaks. *Id*. Finally, LSI asserts that secondary considerations of non-obviousness show that the invention is non-obvious. *Id*. at 2–3. We address LSI's contentions below.

a. *"Variable Ambient Conditions" and "Under "Normal Operating Conditions"*

LSI contends that the inventive feature that differentiates the patents at issue from the prior art is the detection of leaks in the "real-world" setting. PO Resp. 24. The claim limitations requiring detection under "variable ambient conditions" (all challenged claims) and "normal operating conditions" (the challenged claims of the '496 patent). As discussed above, we disagree with LSI's contention that ambient conditions and normal operating conditions require operating under a "full range of normal operating conditions, such as different temperatures or sunlight; and would not encompass prior art systems that could image gases only within a narrow range of field conditions, such as temperature." *Id*. at 27.

We are not persuaded by LSI because the claims at issue do not require imaging gas under any specific conditions. At oral argument, LSI argued that "the claims cover essentially or require a camera that can image a gas under the range of expected ambient—variable ambient conditions around the leak. . . . . [I]n order for this to work in the field that's what it has to do." Tr. 62:7–11. However, LSI concedes that claims at issue do not specify what the normal operating conditions would be and that such conditions would vary depending on the application. Tr. 62:23–24, 63:6–8. LSI's restrictive reading of the claims is not supported by the specifications or claims of the '496 or '813 patents. As discussed above, we conclude that the broadest reasonable construction of "variable ambient conditions" (all challenged claims) and "normal operating conditions" (the challenged claims of the '496 patent) is the ambient conditions of the area around the leak.

Accordingly, we are not persuaded by LSI's argument that the imaging of gas in Strachan and Kulp under artificial or controlled conditions means that it does not teach the claim limitations for "variable ambient conditions" and "normal operating conditions." PO Resp. 28–30. For example, LSI's expert, Dr. Martini, agreed that Kulp only monitored the ambient temperature of the test, and did not strictly control the temperature. Ex. 1032, 42:11–43:7. Indeed, Kulp only discloses a passive IR system that imaged a gas plume whose shape and concentration was controlled as part of the test comparing active and passive IR gas detection. Ex. 1012, 270, 275. Although Kulp uses a sandpaper backdrop in his test, we credit the cross-examination testimony of LSI's expert Dr. Martini, who testified that the sandpaper was used to mimic the earth's surface and was used to maintain consistency between the tests of the active versus passive IR systems. Ex. 1032, 65:5–66:25.

We also disagree with LSI's characterization of Kulp as requiring that certain temperature and/or emissivity differences between gas and the background must always exist to image gas. PO Resp. 15. We agree with FLIR that Kulp's discussion of the differences in temperature between the gas and background acknowledges that some Delta-T (temperature difference between the background and target gas) is necessary for a passive IR system to detect gas. Reply 11 (citing Ex. 1036 ¶¶ 50, 53). We also credit the testimony of FLIR's witness, Dr. Sandsten, over LSI's witness, Dr. Martini, that Kulp imaged gases at different times of the day and at different temperatures. Ex. 1006 ¶ 55.

Furthermore, we are also not persuaded by LSI's proffered testimony characterizing Strachan as only imaging gases under artificially uniform conditions. PO Resp. 28 (citing Ex. 2084 and Ex. 2051). Because the '813 and '496 patent do not specify any particular conditions, LSI's argument and testimony is not consistent with what the claims require. Second, we do not find the testimony of Dr. Martini (Ex. 2084), Dr. Hausler and Dr. Hossack (Ex. 2051) cited by LSI to be persuasive on the disclosure of Strachan. PO Resp. 28. As Dr. Hausler, an LSI expert, stated under cross-examination, the physics of whether gas can be imaged depend on the relative difference in temperature (Delta-T) between the gas and the background, regardless of whether the conditions are controlled or uncontrolled. Ex. 1029, 83:9–84:3. We find that Strachan discloses that practical quality images of hydrocarbon gas can be obtained at various temperatures. Ex. 1008, 497; Reply 9. We also find that a person of ordinary skill in the art would understand that the study disclosed in Strachan is done to explore the feasibility of imaging gas in uncontrolled settings. *See* Ex. 1030, 71:19–24. Accordingly, we find that both Strachan and Kulp disclose the ambient or normal conditions recited in the challenged claims.

b. "visible image of a leak" with a "single filter configuration"

LSI contends that the Merlin Brochure and Merlin User's Guide do not disclose producing a "visible image of a leak" with a "single filter configuration" as recited in the challenged claims. PO Resp. 35–38. We do not agree. First, we do not find convincing the testimony of Dr. Parrish (Ex. 2068) or Dr. Martini (Ex. 2084) regarding the filter wheel location in the Merlin references or whether the Merlin references read on the "single filter configuration" limitation. PO Resp. 35–38.

Second, the Merlin Brochure states that the chemical signatures in aircraft, rocket and missile exhaust can be performed with the "filter wheel option available for the Merlin Lab camera [which] permits wavelength selectivity for spectroscopy and signature analysis." Ex. 1007, 3; Ex. 1036 ¶ 66. We credit FLIR's witness, Dr. Sandsten, that this filter option is described as a cold filter and an InSb detector which supports that a person of ordinary skill in the art would understand that it is located in the single cooling unit of the disclosed camera. Ex. 1007, 6; Ex. 1006 ¶ 71; Ex. 1036 ¶ 71. Indeed, Dr. Parrish, LSI's witness, agrees that the Merlin Brochure describes the cold filter and InSb detector as being located in the Dewar (refrigeration unit). Ex. 1033, 33:14–17. The Merlin User's Guide also contains similar disclosure regarding the cold filter. Ex. 1011, 1–2, 51. Ex. 1039 ¶ 98.

We also disagree with LSI's narrow understanding of a person of ordinary skill in the art as being limited to inserting a filter in the optical path outside of the refrigeration unit. PO Resp. 37. "A person of ordinary skill is also a person of ordinary creativity, not an automaton." *KSR Int'l Co. v. Teleflex, Inc.*, 550 U.S. 398, 421 (2007). We find that the Merlin Brochure or Merlin User's Guide teaches that cold filter can be factory-optimized for wavelength selectivity. Ex. 1007, 2; Reply 7. In addition, we find that FLIR has shown by a preponderance of the evidence that the prior art recognized the practical use of cold filters. Ex. 1036 ¶ 79; *see* Ex. 2027, 114 (stating that the filter should be "cryogenically cooled along with the [detector]" to "achieve the full effect of a narrow-band imaging system").

In sum, we are not persuaded by FLIR that the combination of the Merlin User's Guide with Kulp or the Merlin references with Strachan fails to disclose "a single filter configuration located in the interior of the refrigerated portion" as recited in the challenged claims.

c. "visually detecting the leak based on the visible image under the variable ambient conditions" and "visually detecting a gas leak . . . emanating from a component of a group of components in different locations"

The challenged claims of the '496 patent recite "visually detecting the leak based on the visible image under the variable ambient conditions."

LSI argues that the Merlin Brochure and Strachan cannot "detect" a leak because the references visually image known emissions whose location and composition are controlled. PO Resp. 39–40. As discussed above, we construed "leak" to include known or unknown emissions. We do not agree with LSI that "visually detecting" is not taught in the Merlin Brochure, which discloses imaging of jet exhaust and detection of chemical signatures in the exhaust. Ex. 1007, 3. Thus, LSI's arguments are not well founded.

We also are not persuaded by LSI's argument that Merlin Brochure does not disclose detecting leaks from a group of components. PO Resp. 41–42. We find that the exhaust from an aircraft indicates that the Merlin Brochure discloses monitoring of a group of components that make up the aircraft exhaust. *See* Reply 6 n.2. Indeed, the image in the Merlin Brochure shows imaging half of an aircraft and not only the aircraft's exhaust. Ex. 1007, 3.

d. Reason to Combine and Teaching Away

LSI argues that a person of ordinary skill in the art would not have combined the teachings of the cited references because the references teach away from the passive infrared configuration. We disagree.

"A reference may be said to teach away when a person of ordinary skill, upon reading the reference, would be discouraged from following the path set out in the reference, or would be led in a direction divergent from the path that was taken by the [inventor]." *In re Gurley*, 27 F.3d 551, 553 (Fed. Cir. 1994). A reference does not teach away, however, if it merely expresses a general preference for an alternative invention but does not "criticize, discredit, or otherwise discourage" investigation into the invention claimed. *In re Fulton*, 391 F.3d 1195, 1201 (Fed. Cir. 2004). We will not, however, "read into a reference a teaching away from a process where no such language exists." *DyStar Textilfarben GmbH & Co. Deutschland KG v. C.H. Patrick Co*., 464 F.3d 1356, 1364 (Fed. Cir. 2006).

LSI's evidence that the Merlin references disclose an emission based instrument and that Kulp and Strachan disclose an absorption based instrument, does not show that the references teach away from their combination. Indeed, LSI's citation to the testimony of Dr. Martini does not demonstrate that the Merlin references discourage their combination with Strachan or Kulp. To the contrary, the record shows that a person of ordinary skill in the art would have combined the filter teachings of Strachan with the camera disclosed in the Merlin references. Ex. 1030, 50:1–16, 84:14–85:19, 87:16–88:19, 160:4–14; *see* Ex. 1036 ¶ 22. Although LSI's witness, Dr. Hossack, disputes where the filter would have been placed on a Merlin camera, he does not dispute that Strachan discloses modifying a similar camera to detect gas. Ex. 1030, 50:1–16, 84:14–85:19, 87:16–88:19; 160:4–14.

LSI's argument that the combinations of the Merlin camera disclosed in the Merlin references would destroy the intended functionality of the camera and fundamentally alter its principle of operation is equally unpersuasive. *See* PO Resp. 49–52. LSI has not shown that modification of the Merlin camera as disclosed in the Merlin User's Guide or Brochure would no longer be useful for imaging gas as described. We credit the testimony of Dr. Sandsten in finding that the Merlin MID operates on the principles of thermography before and after modification as disclosed in Kulp and Strachan. Ex. 1036 ¶ 74. In addition, modification of such a camera is expressly taught by Strachan and Kulp. Therefore, regardless of whether the possibility of modifying the Merlin MID camera was disclosed in the Merlin references, the combination of Kulp and/or Strachan with the Merlin references teaches one of ordinary skill in the art that the standard filter could be replaced in a passive IR camera, such as the Merlin MID, to improve imaging. *See, e.g.*, Ex. 1030, 50:1–16, 84:14–85:19, 87:16–88:19; 160:4–14; Reply 15. Indeed, Strachan and Kulp both disclose that gas can be successfully imaged by optimizing the spectral selectivity of a passive IR system using a narrow bandpass filter tuned to the gases of interest. Kulp specifically discloses that a cold filter and Strachan includes a Dewar flask for cooling. Ex. 1008, 493; Ex. 1012, 270. LSI's arguments regarding the modifications of the camera disclosed in the Merlin references fail to address the teachings of the Merlin references in combination with Kulp and/or Strachan. *See In re Keller*, 642 F.2d 413, 426 (CCPA 1981) (attacking references individually cannot demonstrate nonobviousness; rather, the test is what the combined teachings of the references would have suggested to one of ordinary skill in the art).

LSI's contention that the references themselves teach away from their combination is mistaken. *See* PO Resp. 52–61. We are not persuaded by LSI's evidence and testimony that a person of ordinary skill in the art would have selected a different Merlin camera for gas detection and placed a warm filter behind the lens or on a filter wheel rather than insert a narrow bandpass cold filter into the Dewar. PO Resp. 52–57. The fact that the Merlin Brochure discloses multiple cameras for imaging gas does not indicate that it discourages the use of the Merlin MID camera over the uncooled Microbolometer camera. Reply 16. We find that a person of ordinary skill in the art interested in imaging gas within the range of the Merlin MID camera would have modified the filter as disclosed by Strachan and Kulp.

Reply 13. Use of the cold filters disclosed in Strachan and Kulp in the camera of the Merlin references amounts to use of a known element for its known use to achieve an expected result. *KSR*, 550 U.S. at 416.

We also disagree with LSI's argument that Strachan and Kulp both teach that passive IR does not work under normal operating (or variable) ambient conditions, such that a person of ordinary skill in the art would not look to a passive IR system as a solution for gas leak detection in the field. PO Resp. 59. LSI's characterization of Strachan and Kulp is not supported by the plain reading of the references themselves, which do not criticize, discredit, or otherwise discourage use of passive IR. To the contrary, Strachan and Kulp expressly describe imaging gas using passive IR imaging with appropriate narrow cold filters and suggest improvements for future passive IR gas imaging systems. *See* Ex. 1008, 493; Ex. 1012, 270. In addition, LSI's erroneous understanding of Strachan and Kulp is based on the narrow construction of normal operating (or variable) ambient conditions, which we previously rejected.

Finally, we are not persuaded by LSI's argument that active IR or warm filtering are taught in Strachan and Kulp as solutions for imaging gas where the temperature difference between the gas and background is small, (the low Delta-T problem). PO Resp. 60. The claims at issue in the challenged patents do not require any specific operating conditions, nor do they require any specific low or high Delta-T. Thus, we are not persuaded by Dr. Martini's testimony that Kulp and Strachan teach away when there is a low Delta-T. PO Resp. 58–60.

Even assuming that the Merlin Brochure does not disclose modification of the cold filter as LSI argues, such an omission is not teaching away. In addition, with respect to LSI's arguments regarding the permanence of the modification, this also is not teaching away. Choosing where to modify the Merlin MID camera as disclosed in the Merlin Brochure or Merlin User's Guide with the cold filter disclosed in Kulp or Strachan is a simple design choice. The preponderance of the evidence indicates that several prior art references taught putting cold filters narrowband filters inside the refrigerator portion to improve imaging of gas. Ex. 2027, 114; Ex. 1031, 39:22–41:10 (stating that it was known to put the filter and sensor in the same refrigerator portion).

We also do not agree with LSI's frequent reference to FLIR's analysis as being based on hindsight. PO Resp. 23, 61, 66–70. LSI's argument mischaracterizes the disclosures of the prior art, in particular Strachan and Kulp, and ignores the contemporary evidence that filters should be cooled to improve narrowband imaging systems. *See* Ex. 1008, 497; Ex. 1012, 276; Ex. 2027, 114; Ex. 1031, 18:19–19:21, 53:17–54:2; Ex. 1033, 33:14–17, 35:10–36:7; Ex. 1030, 97:21–24; Ex. 1032, 110:20–111:6; Ex. 1039 ¶¶ 98–101; Ex. 1045 ¶ 5.

Based on the full record, we find, by a preponderance of the evidence, that FLIR has provided articulated reasons with rational underpinnings for the proposed combinations of prior art. FLIR's evidence shows that combinations of the Merlin Brochure with Strachan or the Merlin User's Guide with Kulp is the combination of known elements that yield predictable results. *See* Paper 2, 17–18 (citing Ex. 1006 ¶ 55), 20–21 (citing Ex. 1006 ¶ 60) (IPR '065); Paper 2, 37–38 (citing Ex. 1006 ¶ 81) (IPR '411). In addition, we find by a preponderance of the evidence that the prior art demonstrates that it would have been an obvious design choice to one skilled in the art to replace the filters disclosed in Strachan and Kulp to target hydrocarbon gases of interest using the camera disclosed in the Merlin Brochure and Merlin User's Guide. Paper 2, 38–39 (citing Ex. 1006 ¶¶ 81–82) (IPR '411). Accordingly, we do not agree with LSI that FLIR's expert testimony is conclusory. PO Resp. 23, 61, 67–68.

4. Secondary Considerations

LSI argues that there is overwhelming evidence that demonstrates the nonobviousness of the challenged claims. PO Resp. 74–83. In evaluating whether an invention would have been obvious, "[s]uch secondary considerations as commercial success, long felt but unsolved needs, failure of others, etc., might be utilized to give light to the circumstances surrounding the origin of the subject matter sought to be patented." *Graham v. John Deere Co.*, 383 U.S. 1, 17–18 (1966). While the party seeking to demonstrate nonobviousness has the burden to introduce evidence supporting such objective indicia, *see In re Huang*, 100 F.3d 135, 139 (Fed. Cir. 1996), the ultimate burden of persuasion never shifts to Patent Owner, *see* 35 U.S.C. § 316(e).

Objective indicia should be considered along with all of the other evidence in making an obviousness determination. *See Eurand, Inc. v. Mylan Pharm. Inc. (In re Cyclobenzaprine Hydrochloride Extended–Release Capsule Patent Litig.)*, 676 F.3d 1063, 1076–77 (Fed. Cir. 2012) ("It is to be considered as part of all the evidence, not just when the decisionmaker remains in doubt after reviewing the art.") (quoting *Stratoflex, Inc. v. Aeroquip Corp.*, 713 F.2d 1530, 1538–39 (Fed. Cir. 1983)). Factual inquiries for an obviousness determination include secondary considerations based on evaluation and crediting of objective evidence of nonobviousness. *Graham*, 383 U.S. at 17. Secondary considerations may include any of the following: long-felt but unsolved needs, failure of others, unexpected results, commercial success, copying, licensing, and praise.

"For objective evidence to be accorded substantial weight, its proponent must establish a nexus between the evidence and the merits of the claimed invention." *GPAC*, 57 F.3d at 1580. In particular, the objective indicia "must be tied to the novel elements of the claim at issue" and must "'be reasonably commensurate with the scope of the claims.'" *Institut Pasteur & Universite Pierre Et Marie Curie v. Focarino*, 738 F.3d 1337, 1347 (Fed. Cir. 2013) (quoting *Rambus Inc. v. Rea*, 731 F.3d 1248, 1257 (Fed. Cir. 2013)).

LSI provides voluminous evidence the inventor, David Furry, modified an Indigo MID camera (now manufactured by FLIR) to produce a prototype passive infrared camera and achieve unexpected results. PO Resp. 75 (citing Ex. 2068 ¶¶ 15, 18, 30–38; Ex. 2063 ¶¶ 28–29; Ex. 2051 ¶ 80). LSI contends that Mr. Furry's modified camera "allowed the operator to quickly and efficiently identify the source of hydrocarbon leaks, and, perhaps most importantly for field use, *it worked under normal plant operating conditions and variable ambient conditions*, such as variable atmospheric temperatures and wind conditions." PO Resp. 75 (emphasis added) (citing Ex. 2082, 001–002, 005, 007, 013–16, 17–32, 33–38).

As discussed above, the challenged claims do not recite or require any specific conditions. Indeed, the challenged claims require imaging of known or unknown gas under "some" operating conditions. Thus, there is no nexus that is tied to the novel elements of the claims at issue or that are reasonably commensurate with the scope of the claims. Contrary to LSI's position that the Furry camera was the only solution that worked at field trials of leak detection systems (PO Resp. 75–76), the evidence shows that all of the tested imaging systems successfully imaged gas. Ex. 2009, ES-7–ES-9, 2-15, 4-11; Ex. 1036 ¶ 109. The record shows that Kulp and Strachan both successfully imaged gas using passive IR cameras with appropriate cold filters.

Although there is evidence that the FLIR-marketed GasFindIR camera that was initially licensed by Mr. Furry and LSI was a market leader for leak detecting cameras (PO Resp. 76–77), LSI has not shown a sufficient nexus between the novel elements of the claims at issue and the GasFindIR camera or its predecessors.

a. Long Felt Need

LSI contends that the long felt need to find alternatives to the EPA's Method 21 for leak detection and repair and the failure of others to find a workable solution supports its contentions of nonobviousness. PO Resp. 77–78. "Evidence that an invention satisfied a long-felt and unmet need that existed on the patent's filing date is a secondary consideration of nonobviousness." *Perfect Web Techs., Inc. v. InfoUSA, Inc.*, 587 F.3d 1324, 1332 (Fed. Cir. 2009). To show a long-felt need, LSI must introduce evidence to show when such a need first arose and how long this need was felt, and must introduce evidence to show that this need was met by the patented invention. *See id.* "[L]ong-felt need is analyzed as of the date of an articulated identified problem and evidence of efforts to solve that problem." *Tex. Instruments, Inc. v. U.S. Int'l Trade Comm'n*, 988 F.2d 1165, 1178 (Fed. Cir. 1993).

As discussed above, LSI has not provided persuasive evidence showing the intrinsic nexus to the challenged claims and how the claimed invention resolved the long-felt need. Although evidence shows that camera-based solutions have been adopted as alternatives to the EPA's Method 21, the cameras are not limited to LSI's claimed passive camera. Ex. 1034, 90:5–14, 96:2–97:1. Indeed, LSI has not shown that the claimed invention created the alternative to Method 21. Instead, we find that the evidence shows that active and passive IR cameras successfully imaged gas emissions in the API tests and in the prior art. Ex. 2009, ES-7–ES-9, 2-15, 4-11; Ex. 1008; Ex. 1012. The novel functions and features that LSI identifies as necessary "to develop a workable solution for imaging gas leaks" and the failure of others to find a workable solution are not commensurate in scope with the challenged claims, which broadly require imaging gas at some variable ambient conditions.

b. Skepticism of Others and Teaching Away

We are not persuaded by LSI's evidence that the prior art teaches away from the use of modified passive IR cameras for gas leak detection. PO Resp. 78–79. For the reasons discussed above, we do not find that the prior art references teach away from their combination. In addition, LSI's evidence of skepticism of others does not show evidence based on the claimed limitations of the challenged patents. At best, LSI's evidence shows the business-related issues Mr. Furry encountered in obtaining and modifying the passive IR camera. PO Resp. 79 (citing Ex. 2068 ¶¶ 16, 21;

Ex. 2176–Ex. 2178 (deposition exhibits to Ex. 2063)). Indeed, evidence shows that financial considerations in the ordering and modifications prompted the skepticism LSI cites. Ex. 1031, 149:25–152:11. In addition, LSI's evidence of unexpected results when Mr. Furry built his passive IR camera is not commensurate with the scope of the challenged claims, nor do they comport with the prior art, Strachan and Kulp, which disclose imaging gas at variable conditions.

c. Commercial Success, Copying, and Industry Praise

Commercial success is relevant only if it flows from the merits of the invention claimed. *Sjolund v. Musland*, 847 F.2d 1573, 1582 (Fed. Cir. 1988). Thus, a "nexus" is required between the merits of the claimed invention and any objective evidence of nonobviousness offered, if that evidence is to be given substantial weight en route to a conclusion on obviousness. *Stratoflex*, 713 F.2d at 1539; *see also Ormco Corp. v. Align Tech., Inc.*, 463 F.3d 1299, 1311–12 (Fed. Cir. 2006) ("Evidence of commercial success, or other secondary considerations, is only significant if there is a nexus between the claimed invention and the commercial success.").

LSI has presented evidence that FLIR developed and marketed its GasFindIR camera under license and a business development agreement. PO Resp. 81–82. However, LSI has not sufficiently tied the success to the novel elements of the claim at issue. Indeed, the unmodified Merlin MID camera as disclosed in the Merlin references predates the GasFindIR camera and Mr. Furry's Hawk camera, which LSI contends FLIR copied. PO Resp.

81 (stating that FLIR "took the specifications for David Furry's Hawk camera and copied them exactly to make the GasFindIR camera")

Even assuming arguendo that the GasFindIR camera is a copy of Mr. Furry's Hawk Camera and shows evidence of commercial success, the only feature LSI identifies with a nexus to the claimed invention that is not present in the preexisting Merlin MID camera is the use of a narrowband cold filter that is described in marketing material for the GasFindIR camera. PO Resp. 81 (citing Ex. 2082, 020). Such objective evidence of nonobviousness cannot overcome the disclosures that narrowband cold filters were disclosed in the prior art, Kulp and Strachan. *See Tokai Corp. v. Easton Enters., Inc.*, 632 F.3d 1358, 1371 (Fed. Cir. 2011).

LSI also has failed to show that the commercial praise (PO Resp. 82–83) is due to novel aspects of the claimed invention. For example, LSI's emphasis on Mr. Furry inventing the first "working system for imaging gas leaks under variable field conditions" (PO Resp. 83 (citing Ex. 2068 ¶¶ 33–35)) is not commensurate in scope with the claims which are not limited to working under field conditions as LSI asserts.

d. Secondary Consideration Conclusion

Where the evidence shows that the commercial success derived from some aspect of the prior art, or was the result of economic and commercial factors unrelated to the claimed limitations, evidence of commercial success will not be sufficient to demonstrate nonobviousness of a claimed invention. *See In re DBC*, 545 F.3d 1373, 1384 (Fed. Cir. 2008); *see also Tokai*, 632 F.3d at 1369–70 (finding that secondary considerations did not overcome obviousness case).

In the present case, even where evidence of commercial success and copying is present, the nexus between the claimed invention and secondary consideration evidence that LSI relies on is not commensurate with the claims at issue. Having considered the full record, we find that LSI's evidence of secondary considerations, including evidence of commercial success, copying and industry praise, does not outweigh FLIR's strong prima facie case of obviousness. *See Tokai*, 632 F.3d at 1370; *see also Wyers v. Master Lock Co.*, 616 F.3d 1231, 1246 (Fed. Cir. 2010) (discussing cases). LSI's evidence regarding normal field condition success is not commensurate in scope with the patent claims at issue, nor are they compelling enough to rebut the strong prima facie showing of obviousness.

5. Conclusion as to Obviousness

Based on the full record including LSI's evidence of secondary considerations, we find that FLIR has shown by a preponderance of the evidence in IPR2014-00411 that the Merlin Brochure and Strachan disclose claims 1–4, 6, 8–22, 31, 37–40, 42–56, and 58 of the '813 patent; the Merlin Brochure, Strachan, and Piety disclose claims 5 and 7 of the '813 patent; the Merlin Brochure and Strachan disclose claims 1–5 and 9–20 of the '496 patent; the Merlin Brochure, Strachan, and Brengman disclose claim 6 of the '496 patent; and the Merlin Brochure, Strachan, and Hart disclose claim 7 of the '496 patent.

Finally, in IPR2015-00065, FLIR has shown by a preponderance of the evidence that the Merlin Brochure and Strachan disclose claims 23, 25, 28, and 30 of the '813 patent; the Merlin Brochure, Strachan, and Spectrogon disclose claims 27, 32–35, and 41 of the '813 patent; the Merlin

Brochure, Strachan, and OCLI disclose claims 24, 26, 36, and 57 of the ’813 patent; the Merlin User’s Guide and Kulp disclose claims 23, 33, and 35 of the ’813 patent; the Merlin User’s Guide, Kulp, and Spectrogon disclose 25, 27, 28, 30, 32, 34, and 41 of the ’813 patent; and the Merlin User’s Guide, Kulp, and OCLI disclose 24, 26, 36, and 57 of the ’813 patent.

F. Motions to Seal

LSI filed unredacted and redacted versions of the Patent Owner Response (Papers 51 and 64 (IPR ’411)) and redacted exhibits (Ex. 2073, Ex. 2074, and Ex. 2082) along with unopposed Motions to Seal (Papers 48, 61, and 98), a default protective order (Paper 49) and stipulated protective order (Paper 50). Identical redacted papers, unopposed motions, and protective orders were filed in IPR2015-00065 (*see* Papers 34, 35, 36, 37; Ex. 2113, Ex. 2114, Ex. 2122).

There is a strong public policy in favor of making information filed in an *inter partes* review open to the public, especially because the proceeding determines the patentability of claims in an issued patent and, therefore, affects the rights of the public. Under 35 U.S.C. § 316(a)(1) and 37 C.F.R.§ 42.14, the default rule is that all papers filed in an *inter partes* review are open and available for access by the public; however, a party may file a concurrent motion to seal and the information at issue is sealed pending the outcome of the motion. It is only “confidential information” that is protected from disclosure. 35 U.S.C. § 316(a)(7); *see* Office Patent Trial Practice Guide, 77 Fed. Reg. 48,756, 48,760 (Aug. 14, 2012).

The standard for granting a motion to seal is “for good cause.” 37 C.F.R. § 42.54(a). The party moving to seal bears the burden of proof in showing entitlement to the requested relief, and must explain why the information sought to be sealed constitutes confidential information. 37 C.F.R. § 42.20(c). As set forth in the Office Patent Trial Practice Guide, there is an expectation that information will be made public if identified in this Final Written Decision. 77 Fed. Reg. at 48,761.

Based on our review, we conclude that Exhibits 2073, 2074, and 2082 in IPR '411 and Exhibits 2113, 2114, and 2122 in IPR '065 and the unredacted Patent Owner Response currently filed under seal contain confidential business information. The contents of those documents that are asserted as constituting confidential business information have not been relied upon in this Final Written Decision. We are persuaded that good cause exists to have those documents remain under seal.[16]

III. CONCLUSION

In IPR2014-00411, FLIR has demonstrated by a preponderance of the evidence that claims 1–22, 31, 37–40, 42–56, and 58 of the '813 patent, and claims 1–7 and 9–20 of the '496 patent are unpatentable based on the following grounds of unpatentability:

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[16] The sealed documents record will be maintained undisturbed pending the outcome of any appeal taken from this Final Written Decision. At the conclusion of any appeal proceeding, or if no appeal is taken, the documents will be made public. *See* Office Patent Trial Practice Guide, 77 Fed. Reg. at 48,760–61. Either party may file a motion to expunge the sealed documents from the record pursuant to 37 C.F.R. § 42.56. Any such motion will be decided after the conclusion of any appeal proceeding or the expiration of the time period for appealing.

(1) Claims 1–4, 6, 8–22, 31, 37–40, 42–56, and 58 of the ’813 patent under 35 U.S.C. § 103(a) over the Merlin Brochure and Strachan;

(2) Claims 5 and 7 of the ’813 patent under 35 U.S.C. § 103(a) over the Merlin Brochure, Strachan, and Piety;

(3) Claims 1–5 and 9–20 of the ’496 patent under 35 U.S.C. § 103(a) over the Merlin Brochure and Strachan;

(4) Claim 6 of the ’496 patent under 35 U.S.C. § 103(a) over the Merlin Brochure, Strachan, and Brengman; and

(5) Claim 7 of the ’496 patent under 35 U.S.C. § 103(a) over the Merlin Brochure, Strachan, and Hart.

In IPR2015-00065, FLIR has demonstrated by a preponderance of the evidence that claims 23–28, 30, 32–36, 41, and 57 of the ’813 patent are unpatentable based on the following grounds of unpatentability:

(1) Claims 23, 25, 28, and 30 of the ’813 patent under 35 U.S.C. § 103(a) over the Merlin Brochure and Strachan;

(2) Claims 27, 32–35, and 41of the ’813 patent under 35 U.S.C. § 103(a) over the Merlin Brochure, Strachan, and Spectrogon;

(3) Claims 24, 26, 36, and 57 of the ’813 patent under 35 U.S.C. § 103(a) over the Merlin Brochure, Strachan, and OCLI;

(4) Claims 23, 33, and 35 of the ’813 patent under 35 U.S.C. § 103(a) over the Merlin User’s Guide and Kulp;

(5) Claims 25, 27, 28, 30, 32, 34, and 41 of the ’813 patent under 35 U.S.C. § 103(a) over the Merlin User’s Guide, Kulp, and Spectrogon; and

(6) Claims 24, 26, 36, and 57 of the ’813 patent under 35 U.S.C. § 103(a) over the Merlin User’s Guide, Kulp, and OCLI.

IV. ORDER

For the reasons given, it is

ORDERED that, based on a preponderance of the evidence, claims 1–28 and 30–58 of U.S. Patent No. 8,426,813 and claims 1–7 and 9–20 of U.S. Patent No. 8,193,496 are held unpatentable; and

FURTHER ORDERED that, because this is a Final Written Decision, parties to this proceeding seeking judicial review of our Decision must comply with the notice and service requirements of 37 C.F.R. § 90.2.

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US008193496B2

(12) **United States Patent**
Furry

(10) **Patent No.: US 8,193,496 B2**
(45) **Date of Patent: Jun. 5, 2012**

(54) **METHODS FOR PERFORMING INSPECTIONS AND DETECTING CHEMICAL LEAKS USING AN INFRARED CAMERA SYSTEM**

(75) Inventor: **David W. Furry**, Blanket, TX (US)

(73) Assignee: **Leak Surveys, Inc.**, Early, TX (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 684 days.

(21) Appl. No.: **11/298,862**

(22) Filed: **Dec. 10, 2005**

(65) **Prior Publication Data**

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Related U.S. Application Data

(63) Continuation of application No. PCT/US2004/012946, filed on Apr. 26, 2004.

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(51) **Int. Cl.**
G01J 5/02 (2006.01)

(52) **U.S. Cl.** **250/330**; 250/339.03

(58) **Field of Classification Search** 250/330, 250/339.03
See application file for complete search history.

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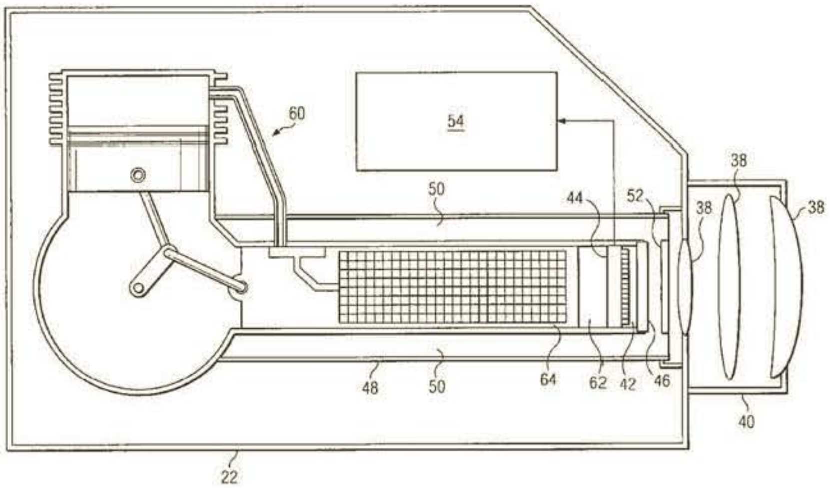
(57) **ABSTRACT**

A method of visually detecting a leak of a chemical emanating from a component. The method includes: aiming a passive infrared camera system towards the component; filtering an infrared image with an optical bandpass filter, the infrared image being that of the leak; after the infrared image passes through the lens and optical bandpass filter, receiving the filtered infrared image with an infrared sensor device; electronically processing the filtered infrared image received by the infrared sensor device to provide a visible image representing the filtered infrared image; and visually identifying the leak based on the visible image. The passive infrared camera system includes: a lens; a refrigerated portion including therein the infrared sensor device and the optical bandpass filter (located along an optical path between the lens and the infrared sensor device). At least part of a pass band for the optical bandpass filter is within an absorption band for the chemical.

20 Claims, 31 Drawing Sheets



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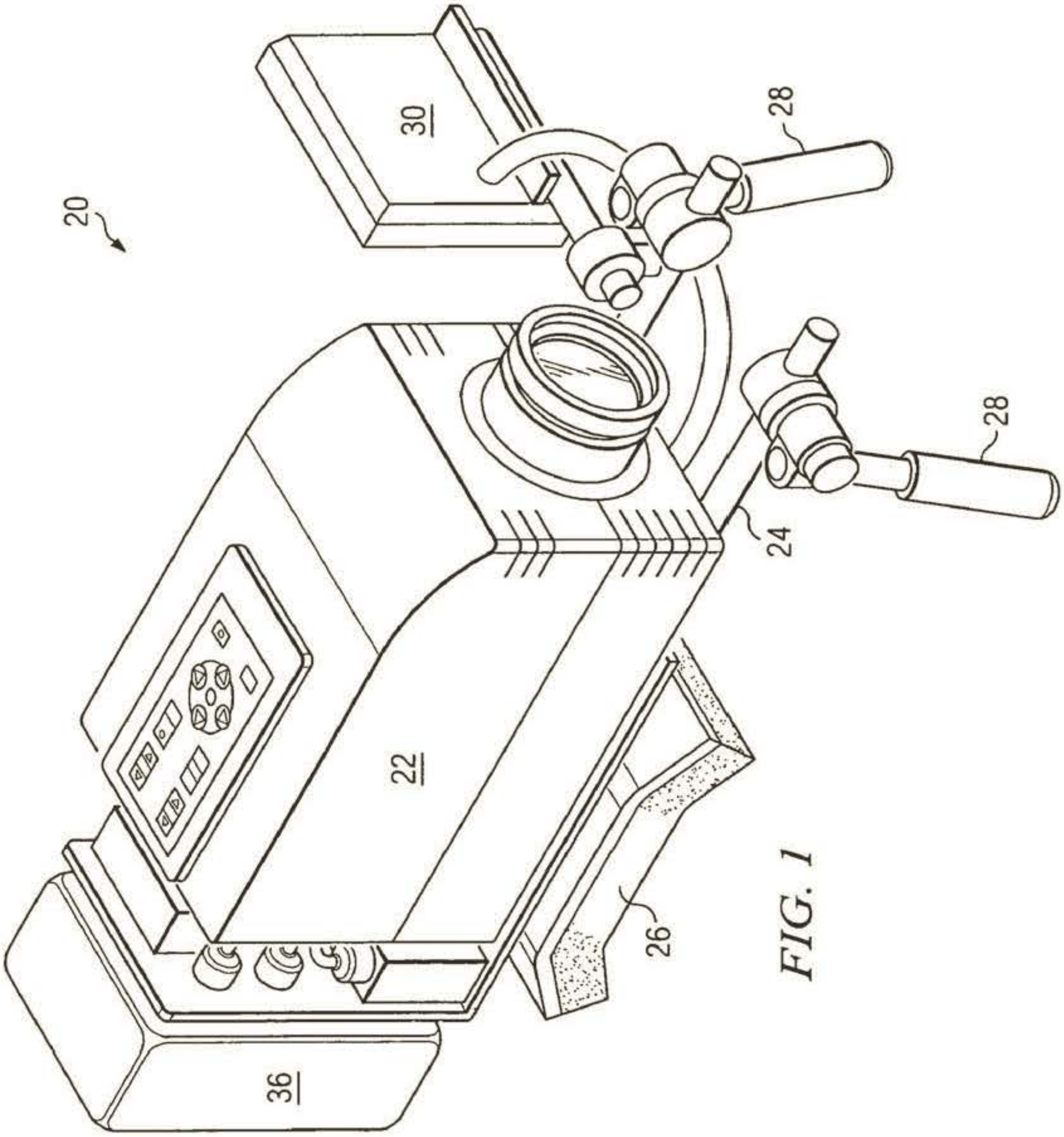

FIG. 1

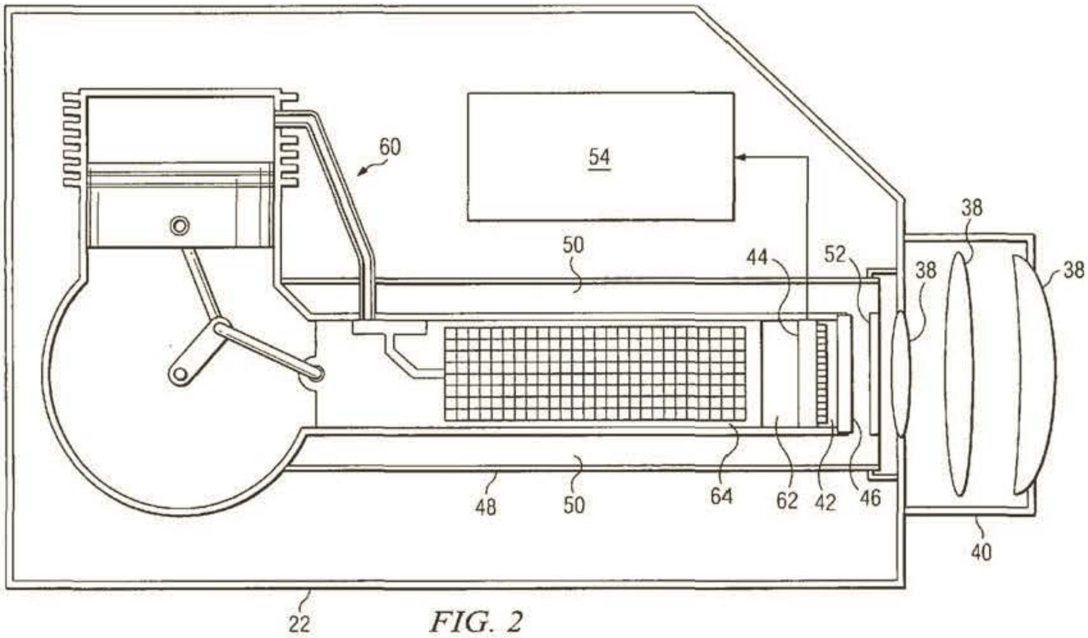

FIG. 2

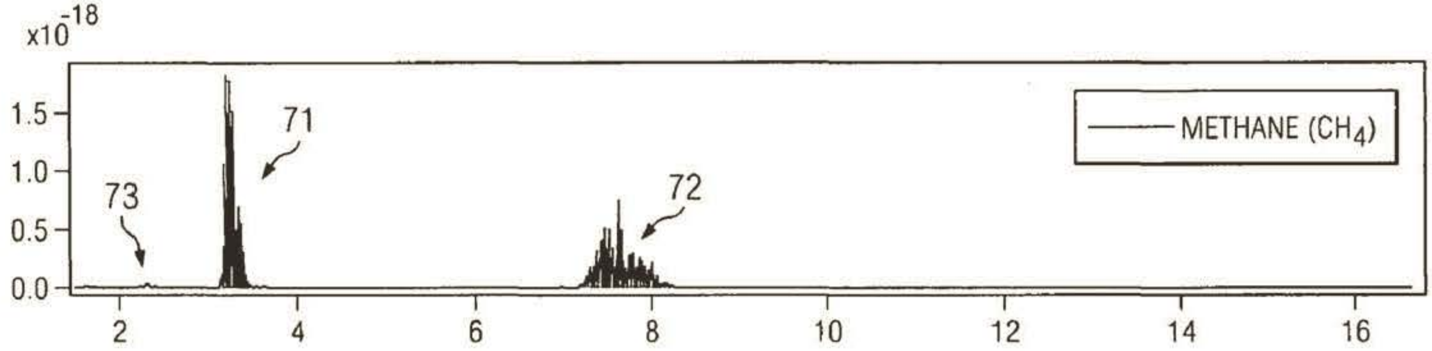
x10^-18
1.5
1.0
0.5
0.0
2
4
6
8
10
12
14
16
73
71
72
METHANE (CH4)

FIG. 3A

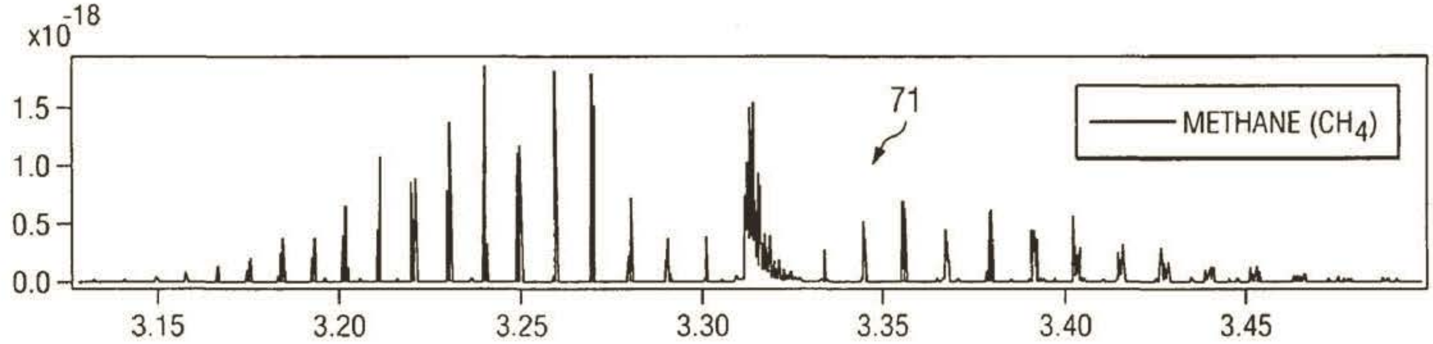
x10^-18
1.5
1.0
0.5
0.0
3.15
3.20
3.25
3.30
3.35
3.40
3.45
71
METHANE (CH4)

FIG. 3B

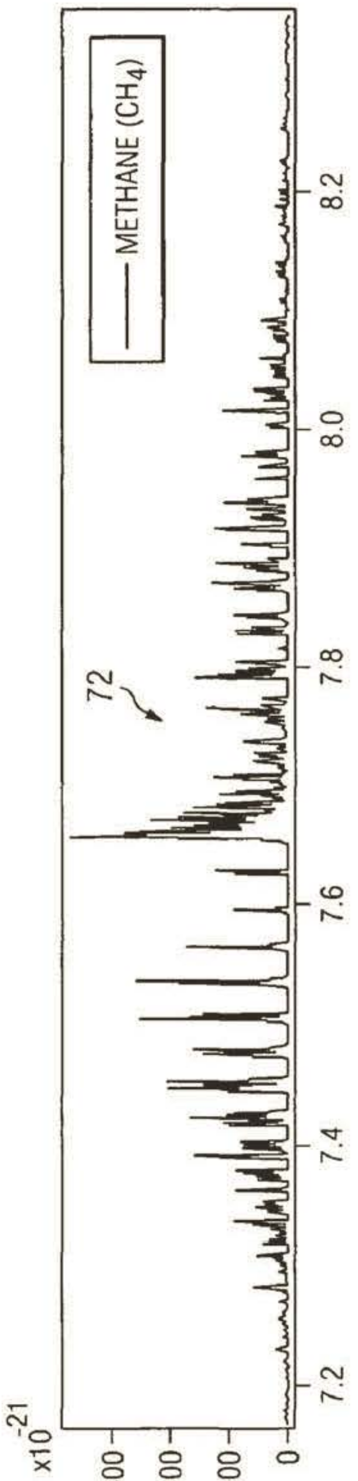
METHANE (CH_4)
72
x10^{-21}
600
400
200
0
7.2
7.4
7.6
7.8
8.0
8.2

FIG. 3C

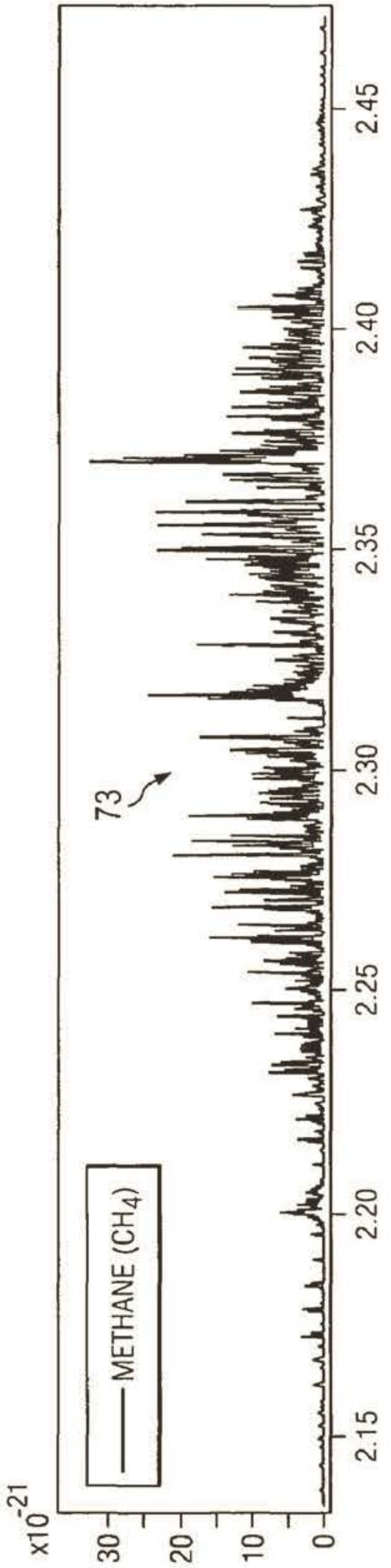
METHANE (CH_4)
73
x10^{-21}
30
20
10
0
2.15
2.20
2.25
2.30
2.35
2.40
2.45

FIG. 3D

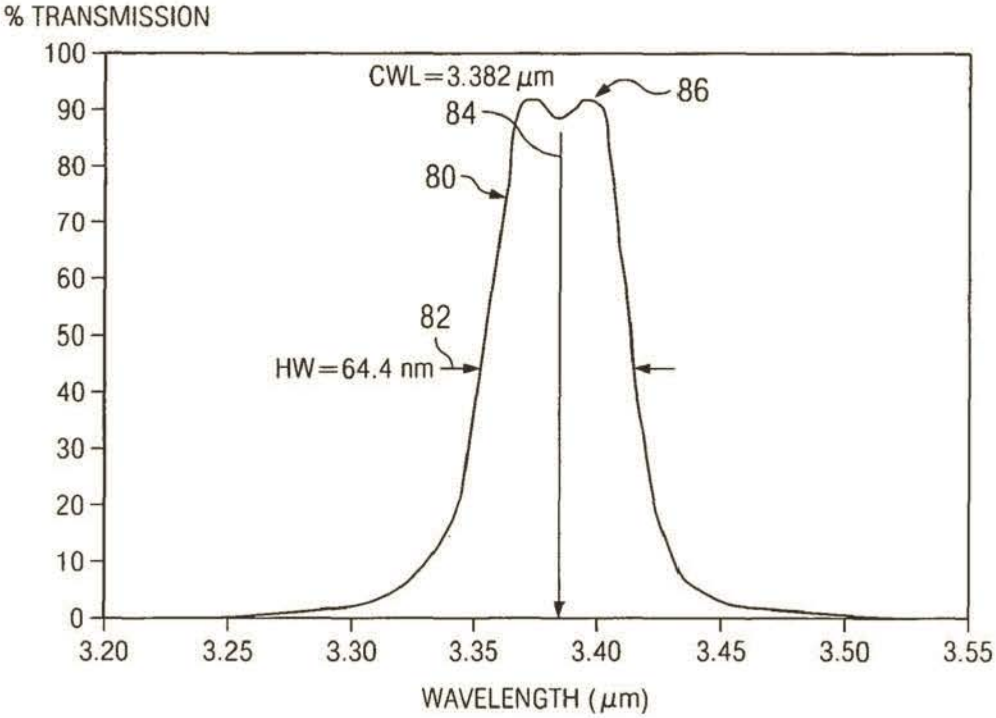
% TRANSMISSION
100
90
80
70
60
50
40
30
20
10
0
CWL=3.382 μm
86
84
80
82
HW=64.4 nm
3.20
3.25
3.30
3.35
3.40
3.45
3.50
3.55
WAVELENGTH (μm)

FIG. 4

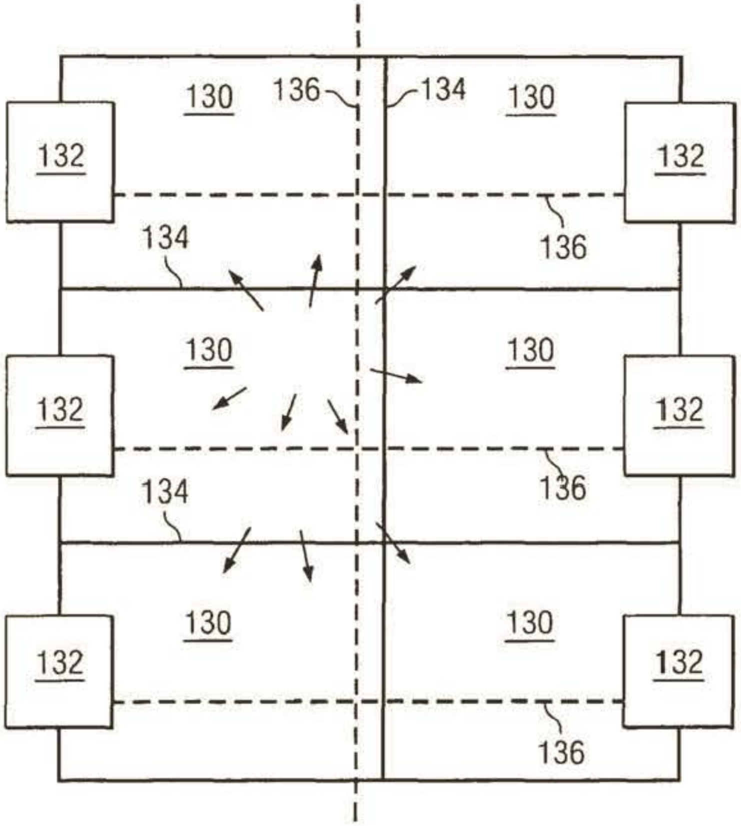
130
136
134
130
132
132
136
134
130
130
132
132
136
134
130
130
132
132
136

FIG. 22

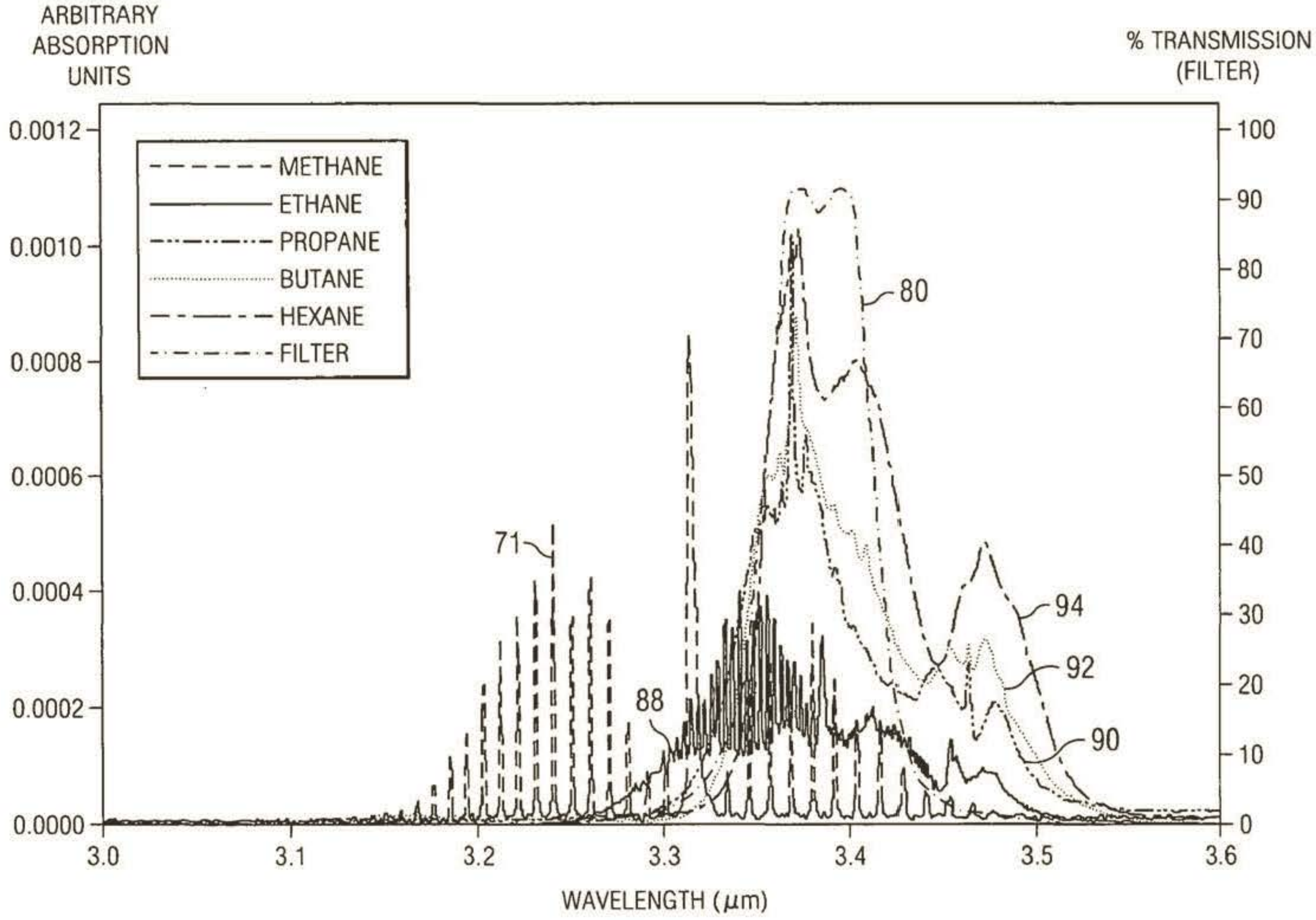
ARBITRARY ABSORPTION UNITS
% TRANSMISSION (FILTER)
METHANE
ETHANE
PROPANE
BUTANE
HEXANE
FILTER
0.0012
0.0010
0.0008
0.0006
0.0004
0.0002
0.0000
100
90
80
70
60
50
40
30
20
10
0
3.0
3.1
3.2
3.3
3.4
3.5
3.6
WAVELENGTH (μm)
71
80
88
94
92
90

FIG. 5

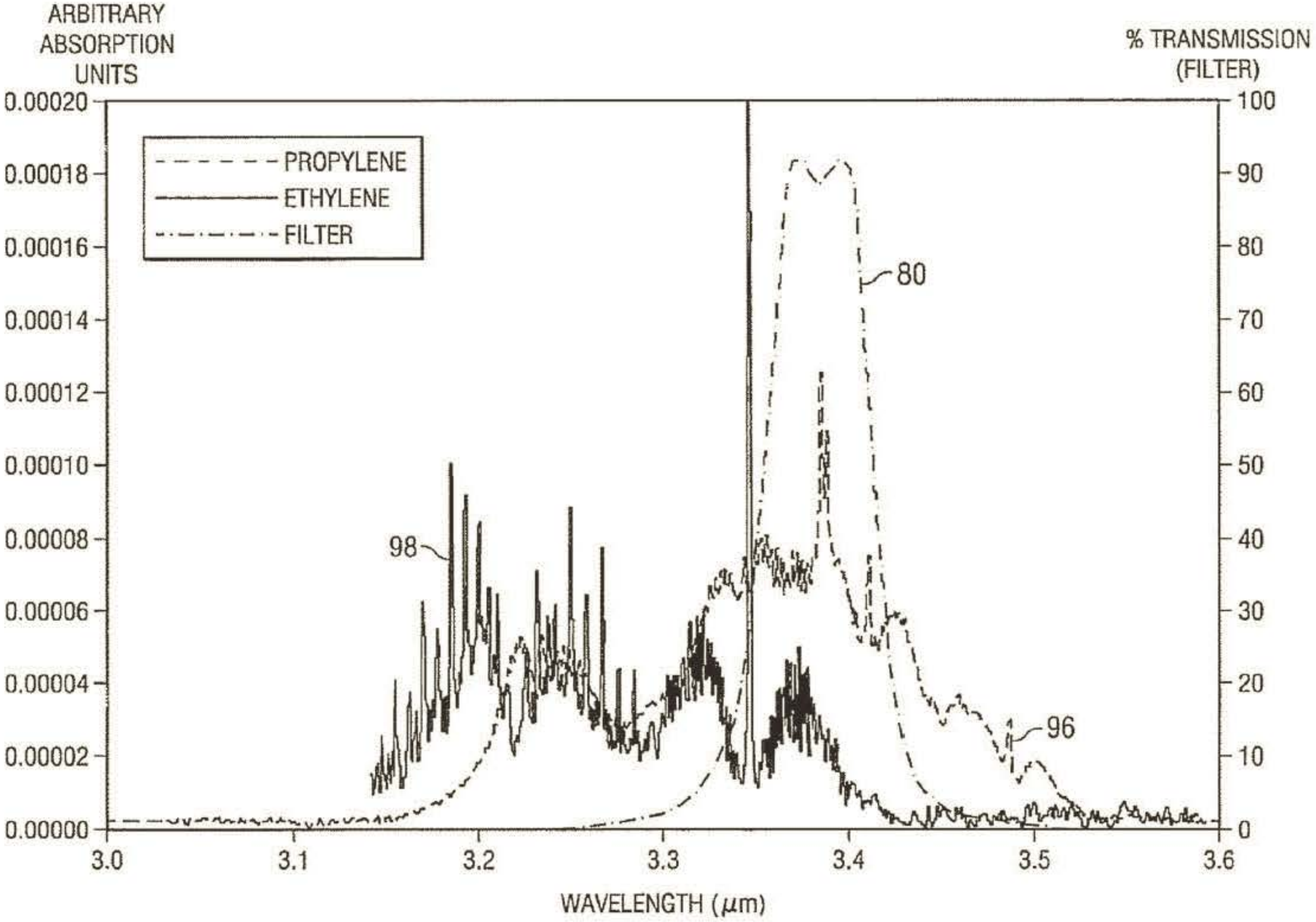
ARBITRARY ABSORPTION UNITS
% TRANSMISSION (FILTER)
0.00020
0.00018
0.00016
0.00014
0.00012
0.00010
0.00008
0.00006
0.00004
0.00002
0.00000
100
90
80
70
60
50
40
30
20
10
0
PROPYLENE
ETHYLENE
FILTER
80
98
96
3.0
3.1
3.2
3.3
3.4
3.5
3.6
WAVELENGTH (μm)

FIG. 6

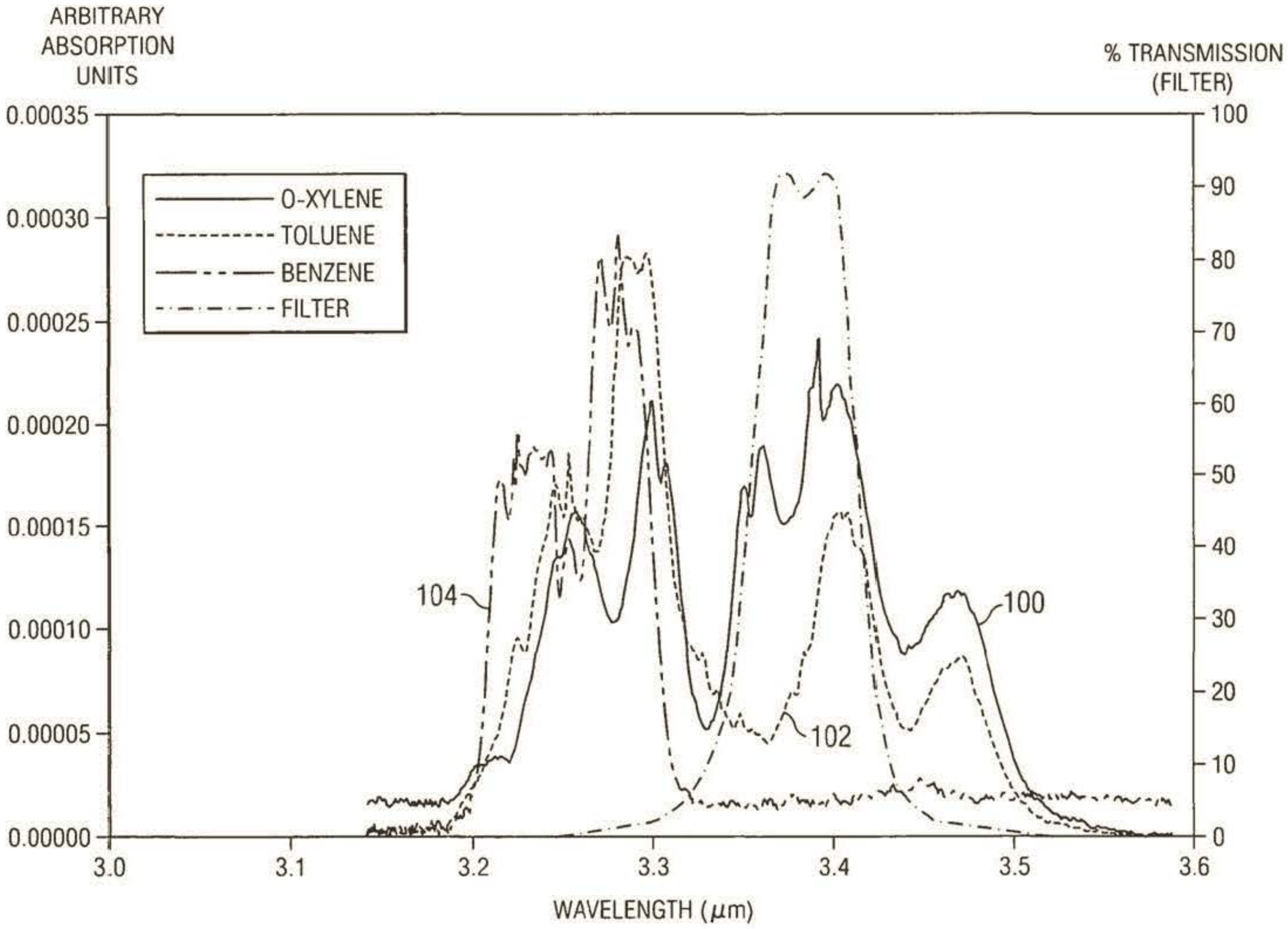
ARBITRARY ABSORPTION UNITS
% TRANSMISSION (FILTER)
0.00035
0.00030
0.00025
0.00020
0.00015
0.00010
0.00005
0.00000
100
90
80
70
60
50
40
30
20
10
0
O-XYLENE
TOLUENE
BENZENE
FILTER
104
100
102
3.0
3.1
3.2
3.3
3.4
3.5
3.6
WAVELENGTH (μm)

FIG. 7

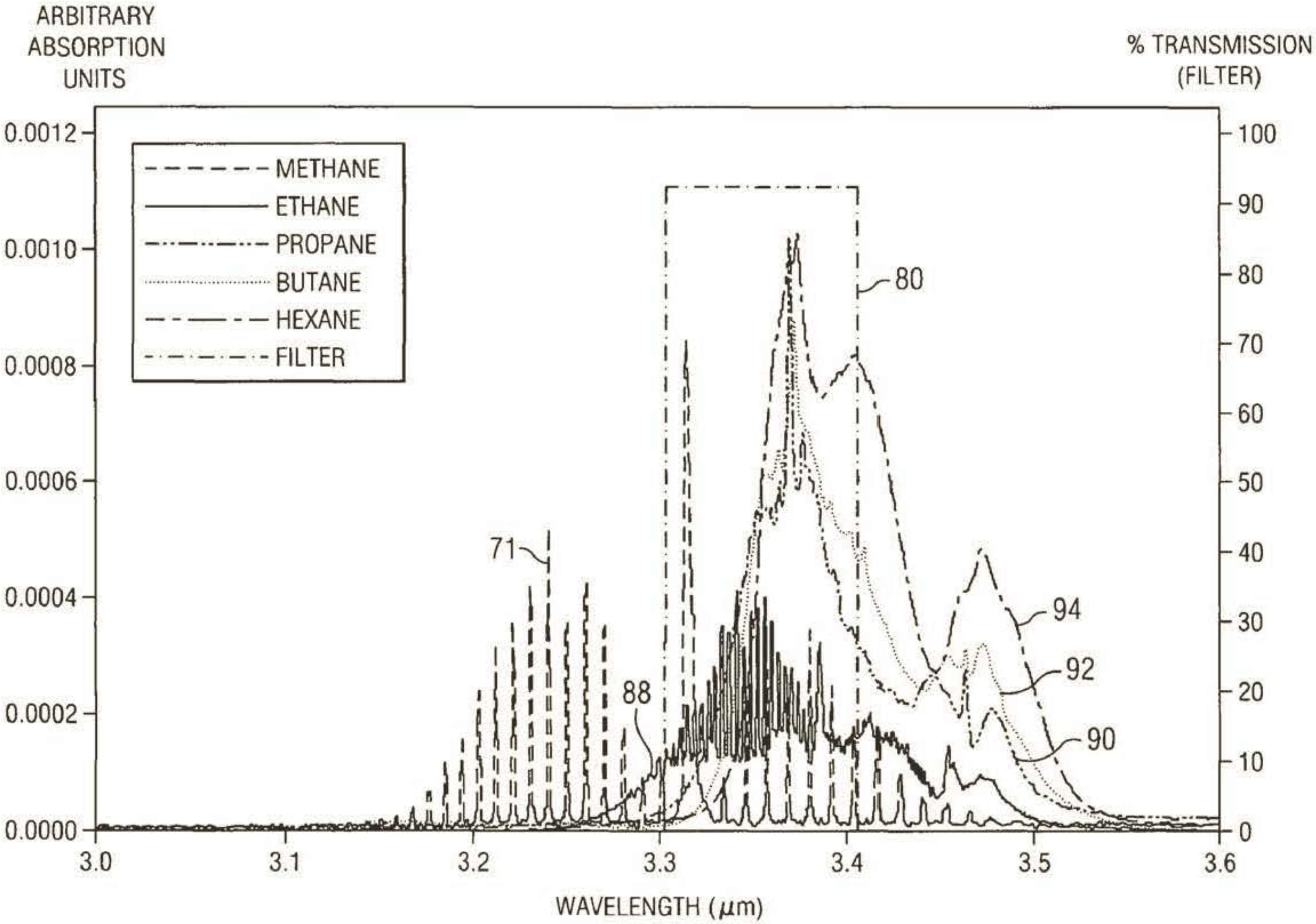
ARBITRARY ABSORPTION UNITS
% TRANSMISSION (FILTER)
METHANE
ETHANE
PROPANE
BUTANE
HEXANE
FILTER
0.0012
0.0010
0.0008
0.0006
0.0004
0.0002
0.0000
100
90
80
70
60
50
40
30
20
10
0
3.0
3.1
3.2
3.3
3.4
3.5
3.6
WAVELENGTH (μm)
71
80
88
94
92
90

FIG. 8

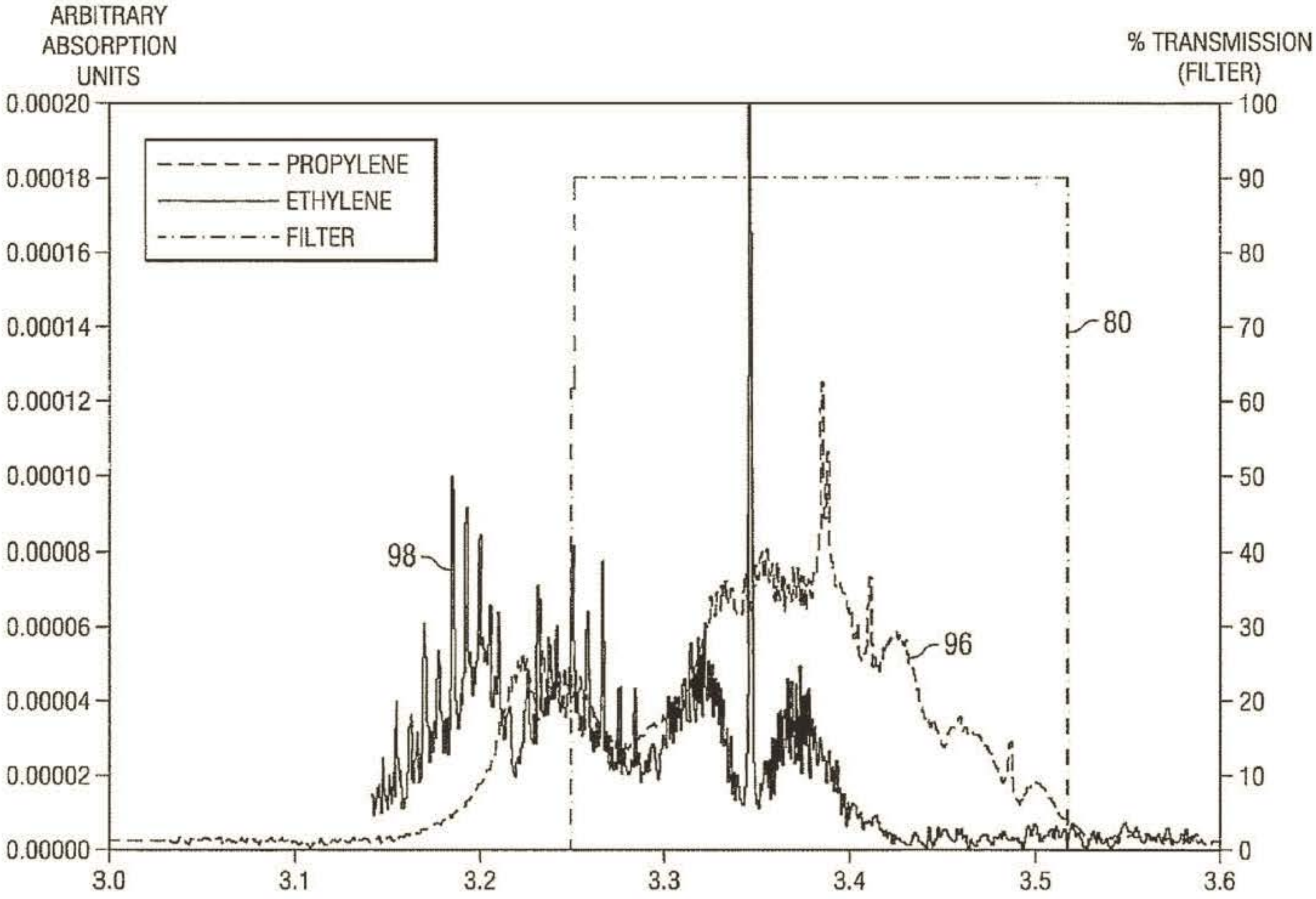
ARBITRARY ABSORPTION UNITS
% TRANSMISSION (FILTER)
PROPYLENE
ETHYLENE
FILTER
0.00020
0.00018
0.00016
0.00014
0.00012
0.00010
0.00008
0.00006
0.00004
0.00002
0.00000
100
90
80
70
60
50
40
30
20
10
0
80
98
96
3.0
3.1
3.2
3.3
3.4
3.5
3.6
WAVELENGTH (μm)

FIG. 9

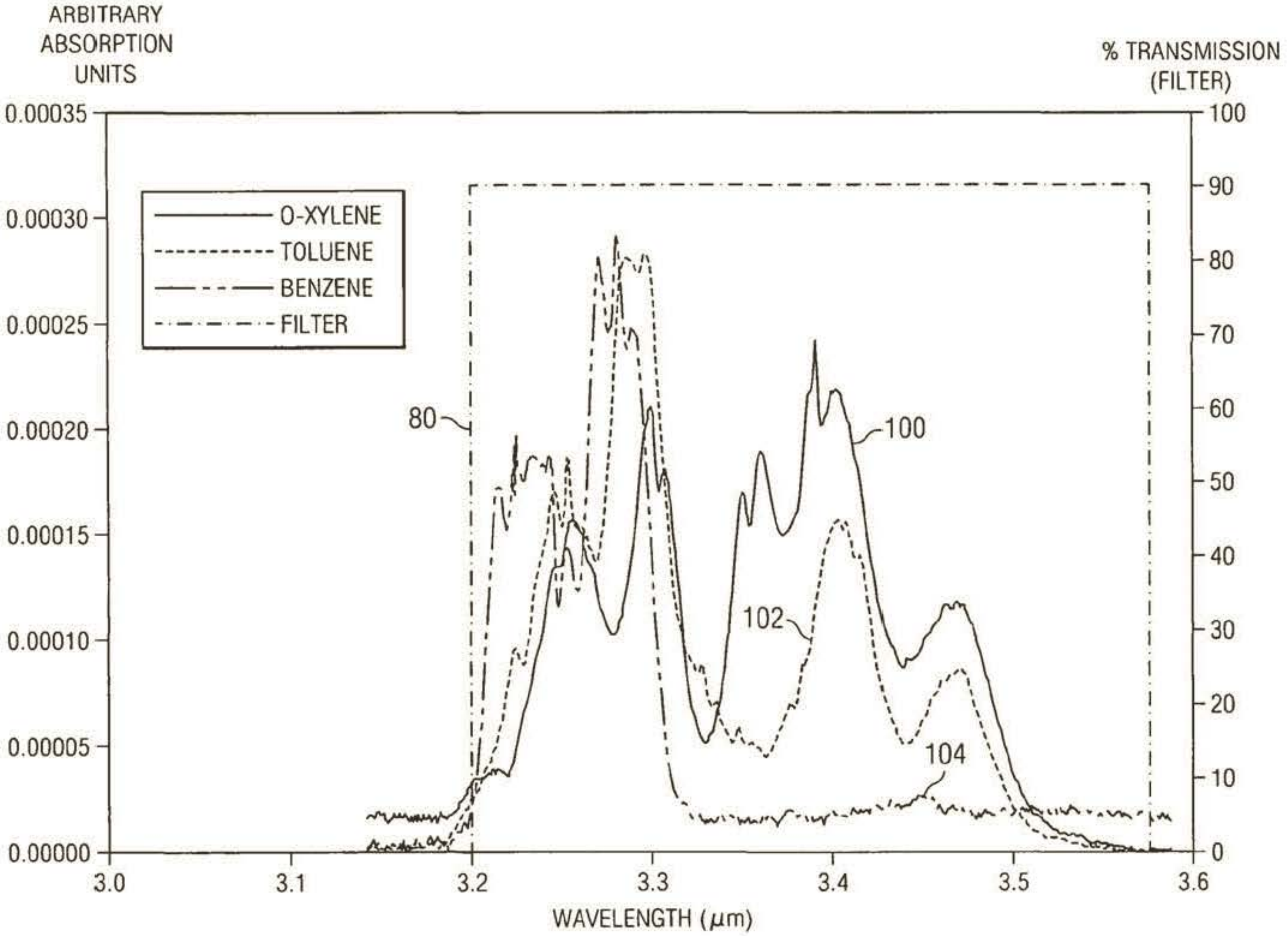
ARBITRARY ABSORPTION UNITS
% TRANSMISSION (FILTER)
0.00035
0.00030
0.00025
0.00020
0.00015
0.00010
0.00005
0.00000
100
90
80
70
60
50
40
30
20
10
0
O-XYLENE
TOLUENE
BENZENE
FILTER
80
100
102
104
3.0
3.1
3.2
3.3
3.4
3.5
3.6
WAVELENGTH (μm)

FIG. 10

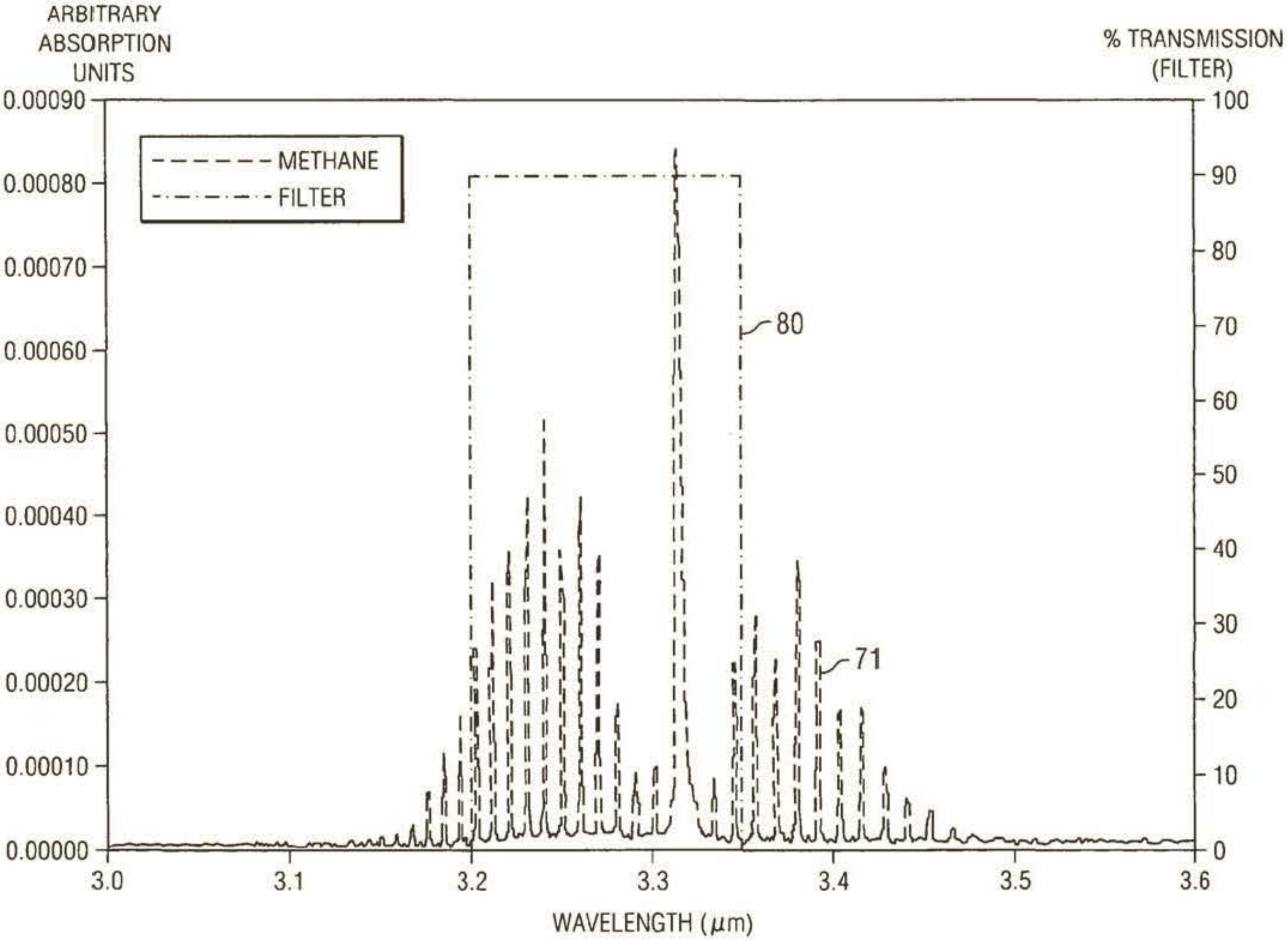
ARBITRARY ABSORPTION UNITS
% TRANSMISSION (FILTER)
METHANE
FILTER
0.00090
0.00080
0.00070
0.00060
0.00050
0.00040
0.00030
0.00020
0.00010
0.00000
100
90
80
70
60
50
40
30
20
10
0
80
71
3.0
3.1
3.2
3.3
3.4
3.5
3.6
WAVELENGTH (μm)

FIG. 11

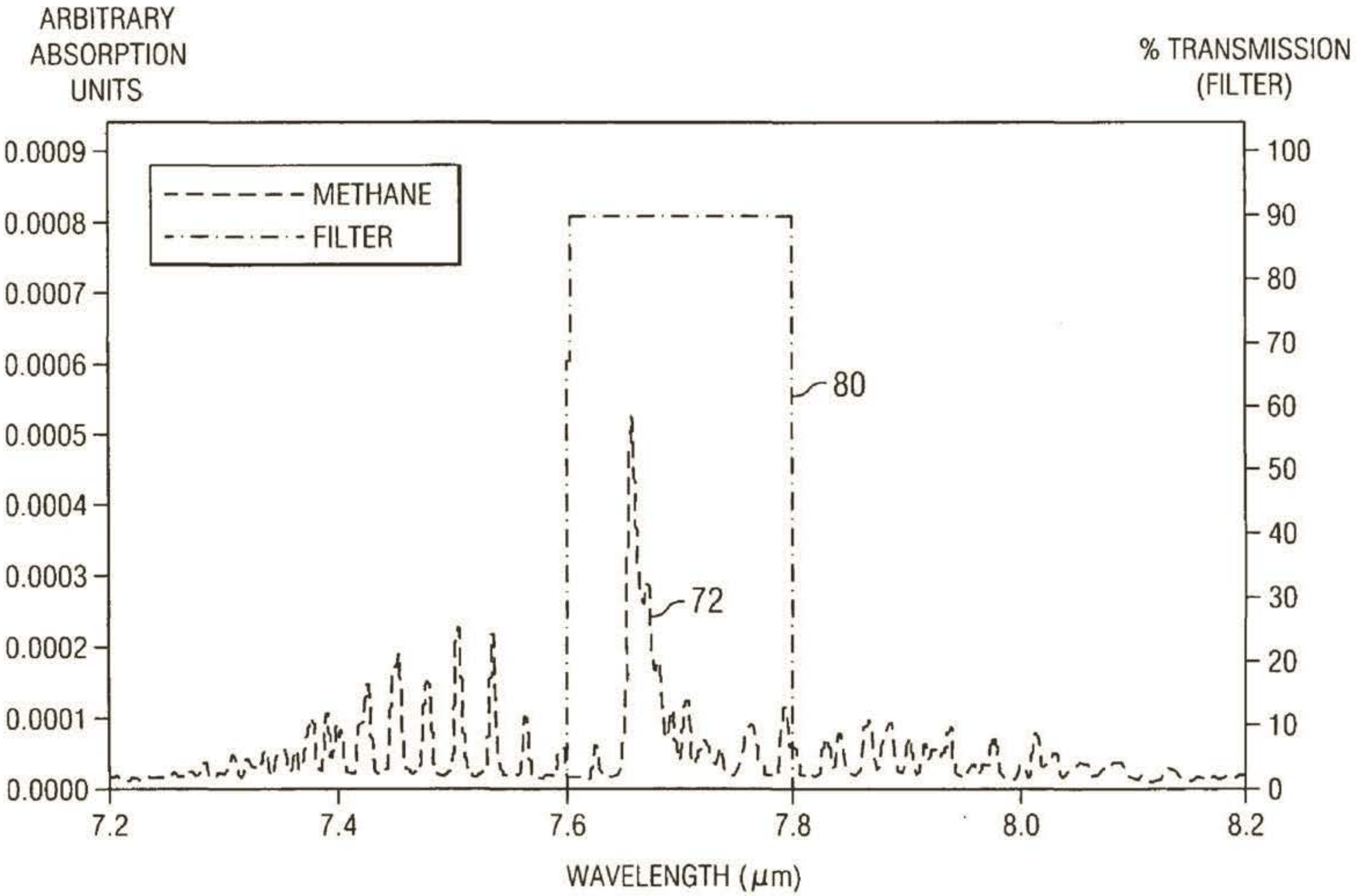
ARBITRARY ABSORPTION UNITS
% TRANSMISSION (FILTER)
METHANE
FILTER
0.0009
0.0008
0.0007
0.0006
0.0005
0.0004
0.0003
0.0002
0.0001
0.0000
100
90
80
70
60
50
40
30
20
10
0
80
72
7.2
7.4
7.6
7.8
8.0
8.2
WAVELENGTH (μm)

FIG. 12

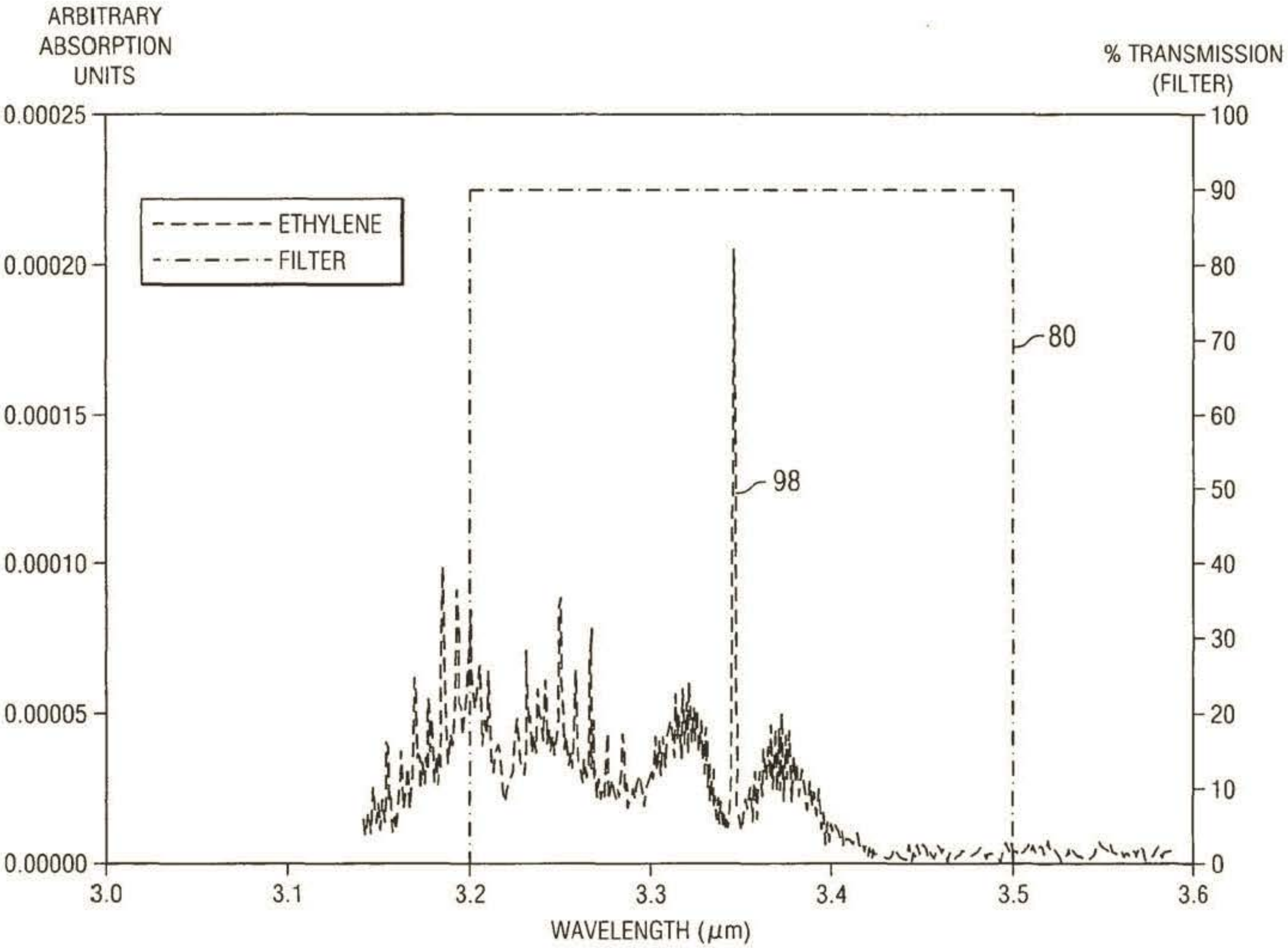
ARBITRARY ABSORPTION UNITS
% TRANSMISSION (FILTER)
0.00025
0.00020
0.00015
0.00010
0.00005
0.00000
100
90
80
70
60
50
40
30
20
10
0
ETHYLENE
FILTER
80
98
3.0
3.1
3.2
3.3
3.4
3.5
3.6
WAVELENGTH (μm)

FIG. 13

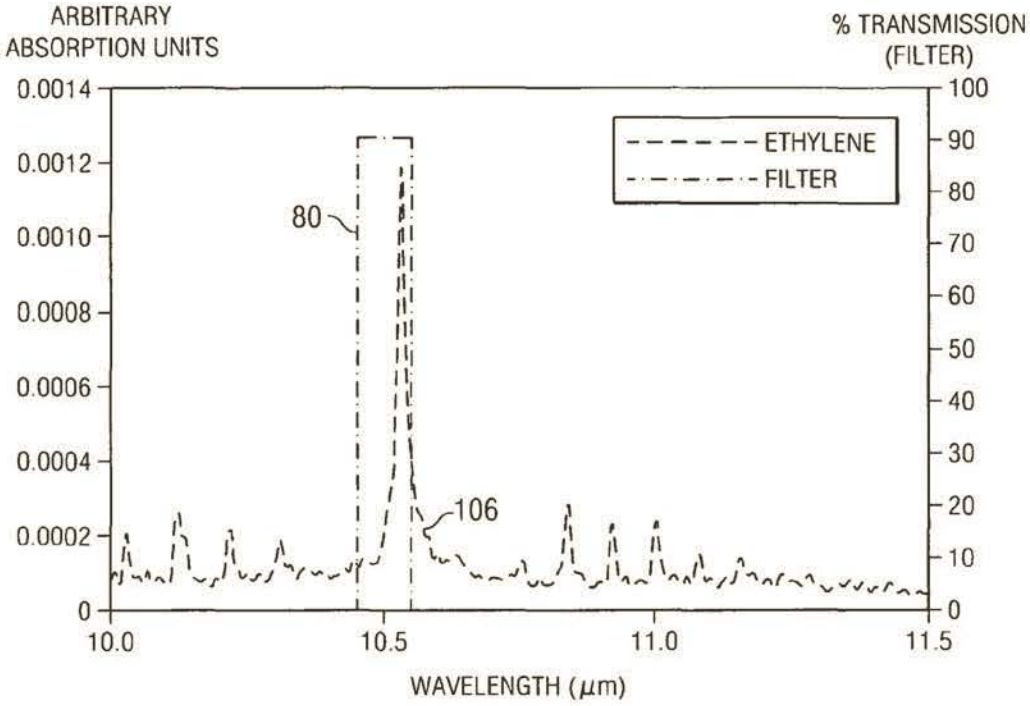
ARBITRARY ABSORPTION UNITS
% TRANSMISSION (FILTER)
0.0014
0.0012
0.0010
0.0008
0.0006
0.0004
0.0002
0
100
90
80
70
60
50
40
30
20
10
0
ETHYLENE
FILTER
80
106
10.0
10.5
11.0
11.5
WAVELENGTH (µm)

FIG. 14

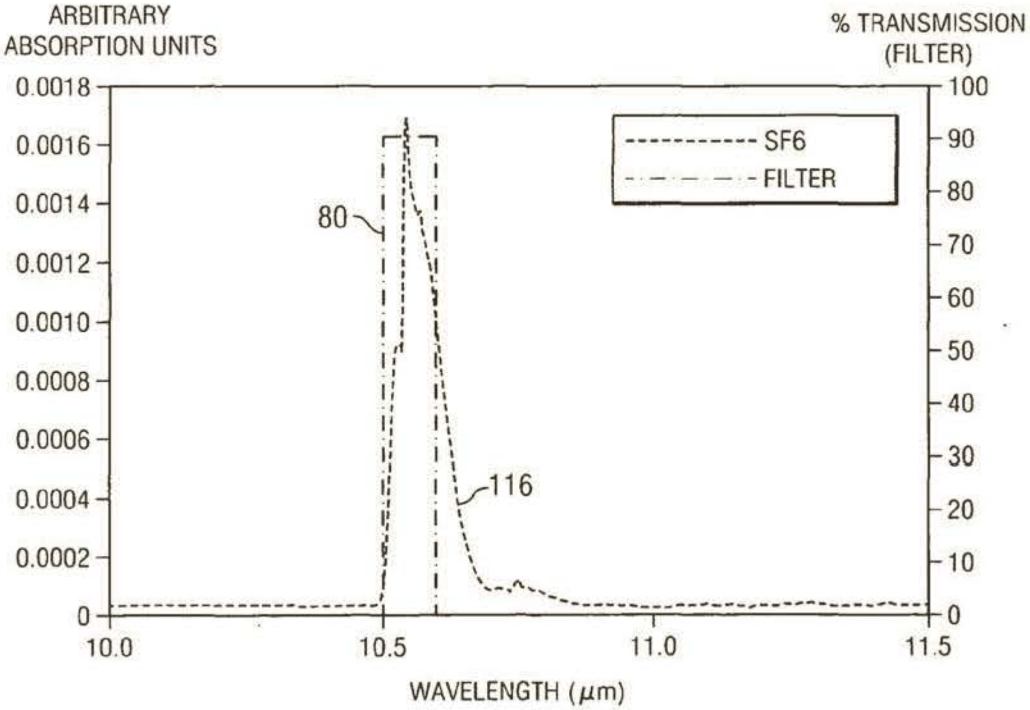
ARBITRARY ABSORPTION UNITS
% TRANSMISSION (FILTER)
0.0018
0.0016
0.0014
0.0012
0.0010
0.0008
0.0006
0.0004
0.0002
0
100
90
80
70
60
50
40
30
20
10
0
SF6
FILTER
80
116
10.0
10.5
11.0
11.5
WAVELENGTH (µm)

FIG. 19

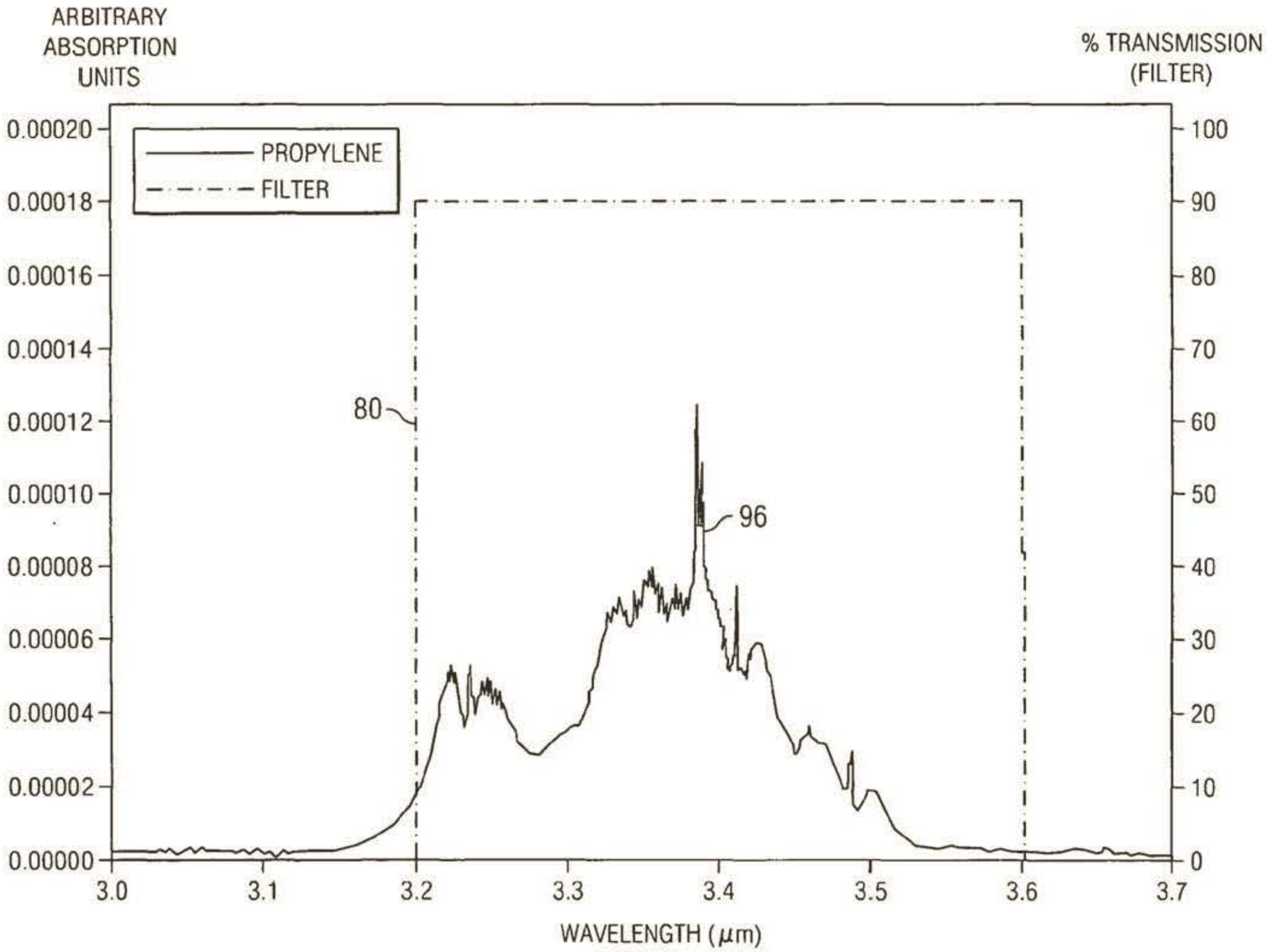
ARBITRARY ABSORPTION UNITS
% TRANSMISSION (FILTER)
PROPYLENE
FILTER
0.00020
0.00018
0.00016
0.00014
0.00012
0.00010
0.00008
0.00006
0.00004
0.00002
0.00000
100
90
80
70
60
50
40
30
20
10
0
80
96
3.0
3.1
3.2
3.3
3.4
3.5
3.6
3.7
WAVELENGTH (μm)

FIG. 15

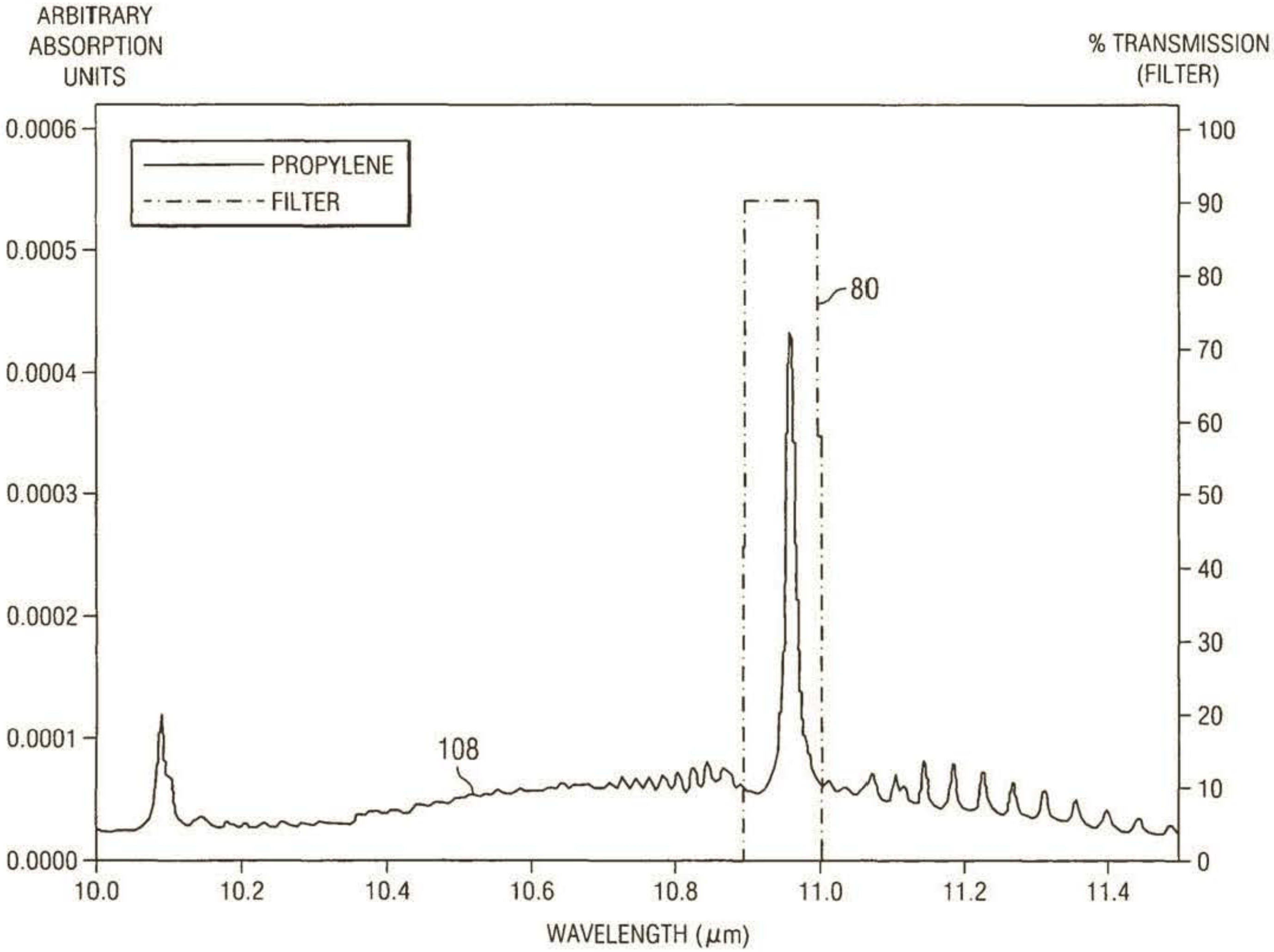
ARBITRARY ABSORPTION UNITS
% TRANSMISSION (FILTER)
PROPYLENE
FILTER
0.0006
0.0005
0.0004
0.0003
0.0002
0.0001
0.0000
100
90
80
70
60
50
40
30
20
10
0
80
108
10.0
10.2
10.4
10.6
10.8
11.0
11.2
11.4
WAVELENGTH (μm)

FIG. 16

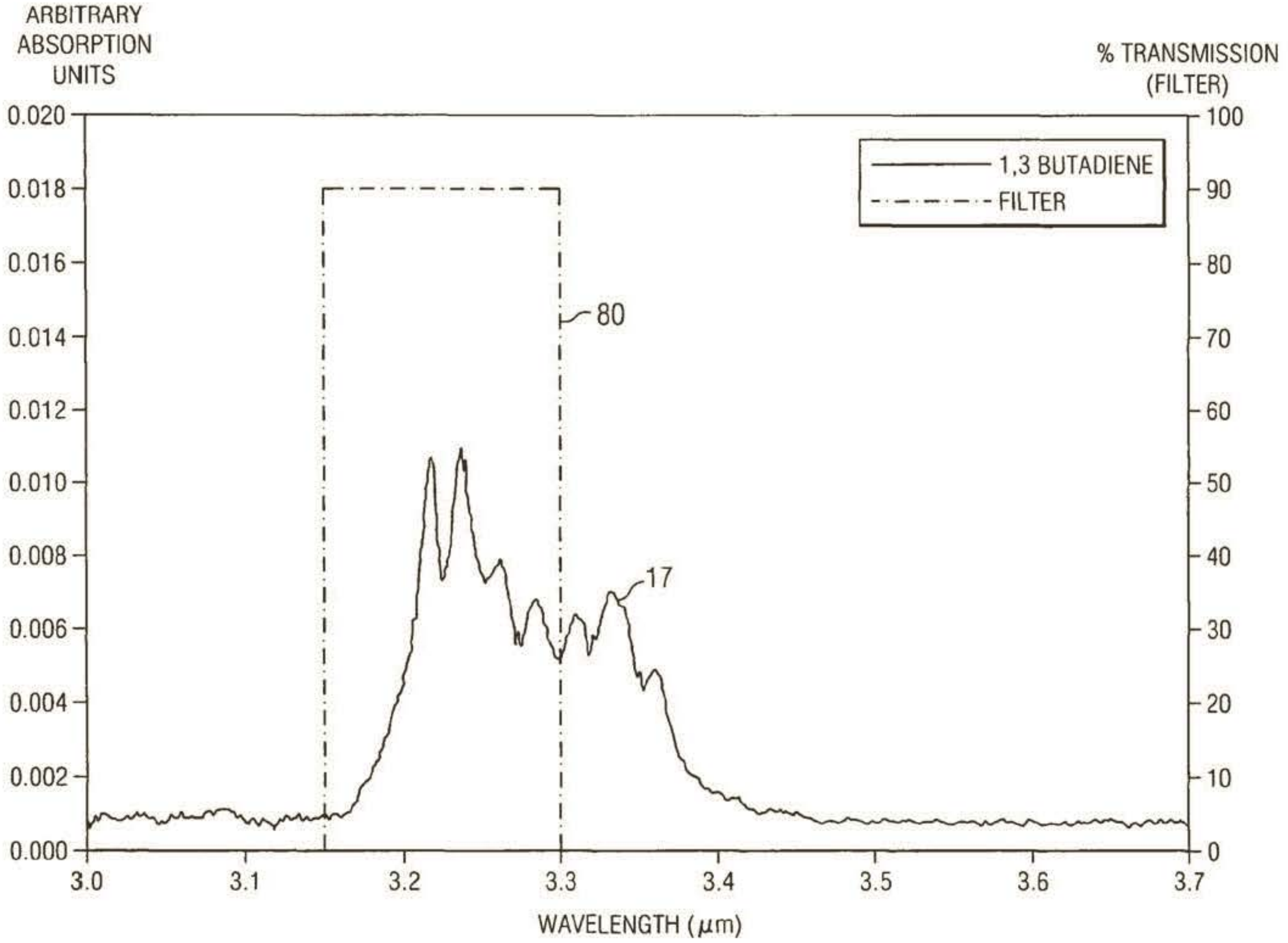
ARBITRARY ABSORPTION UNITS
% TRANSMISSION (FILTER)
0.020
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
100
90
80
70
60
50
40
30
20
10
0
1,3 BUTADIENE
FILTER
80
17
3.0
3.1
3.2
3.3
3.4
3.5
3.6
3.7
WAVELENGTH (μm)

FIG. 17

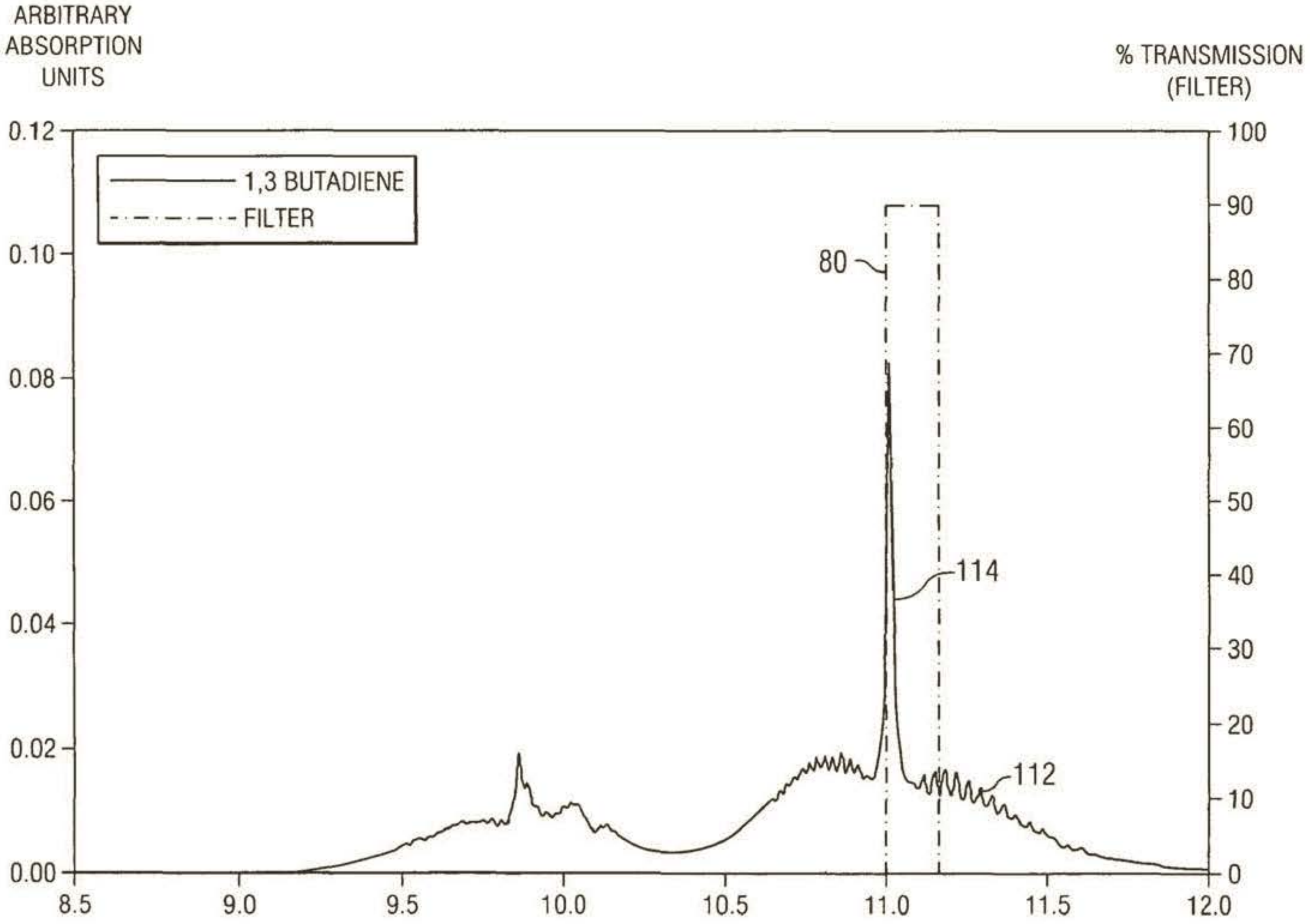
ARBITRARY ABSORPTION UNITS
% TRANSMISSION (FILTER)
1,3 BUTADIENE
FILTER
0.12
0.10
0.08
0.06
0.04
0.02
0.00
100
90
80
70
60
50
40
30
20
10
0
80
114
112
8.5
9.0
9.5
10.0
10.5
11.0
11.5
12.0
WAVELENGTH (μm)

FIG. 18

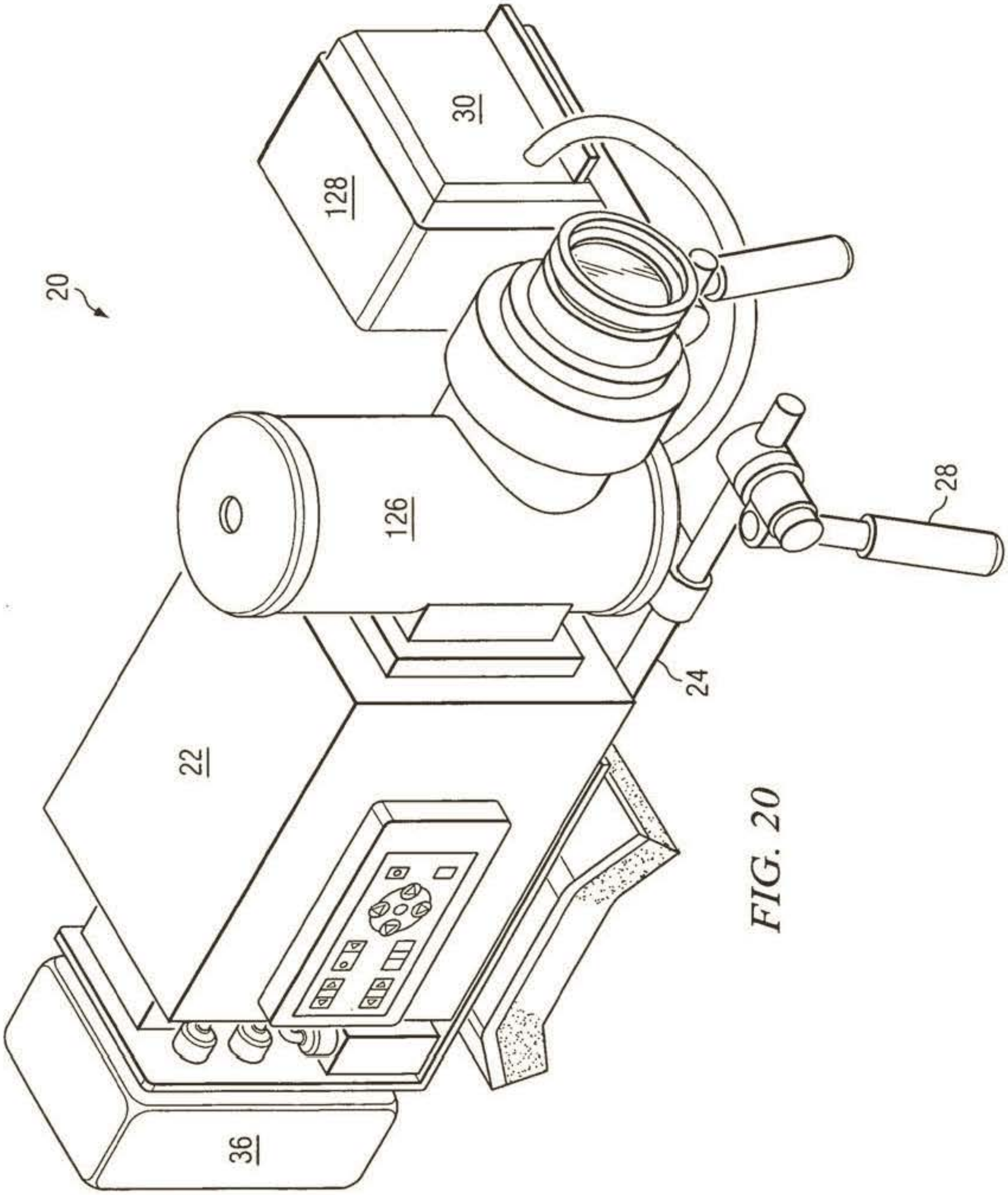

FIG. 20

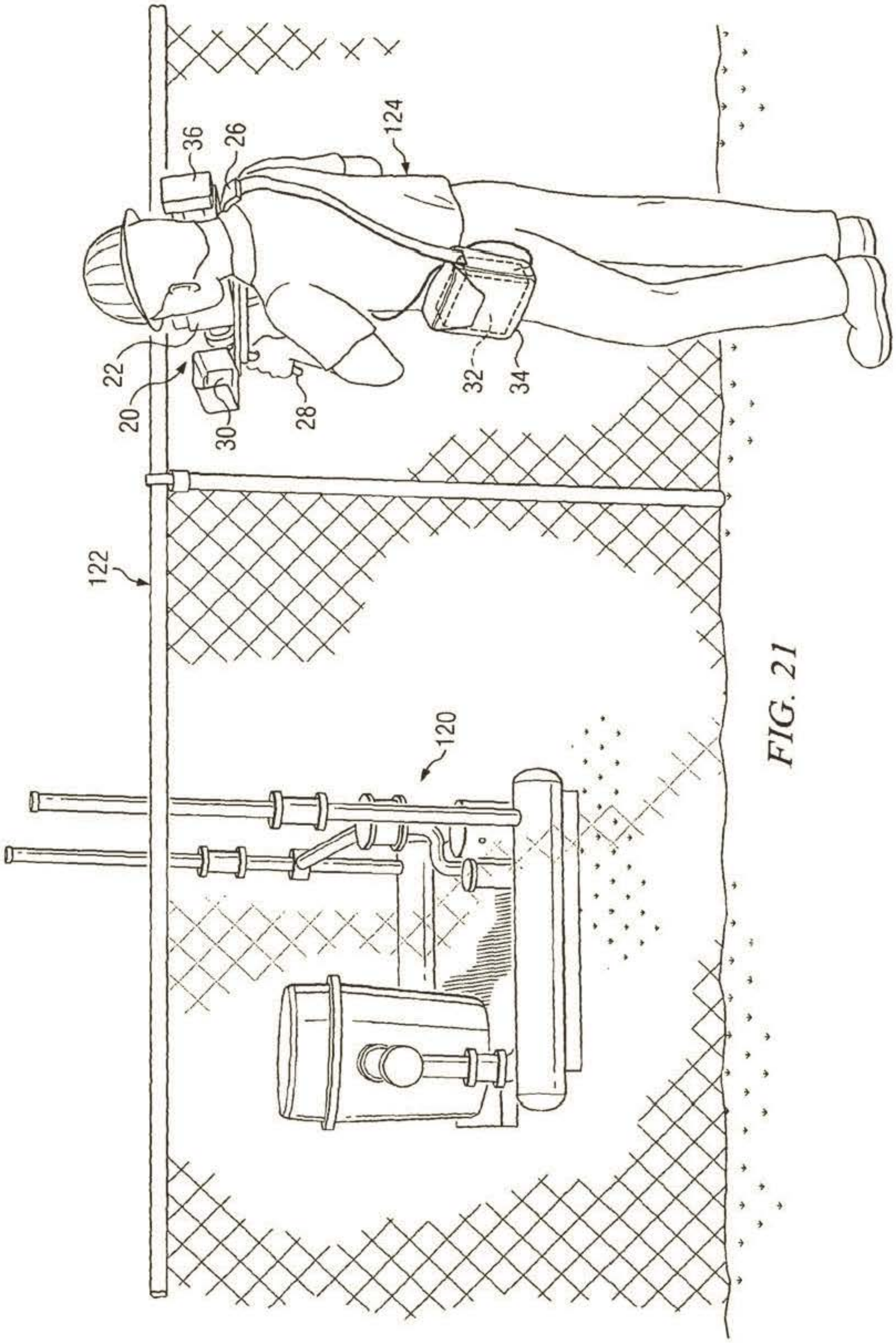

FIG. 21

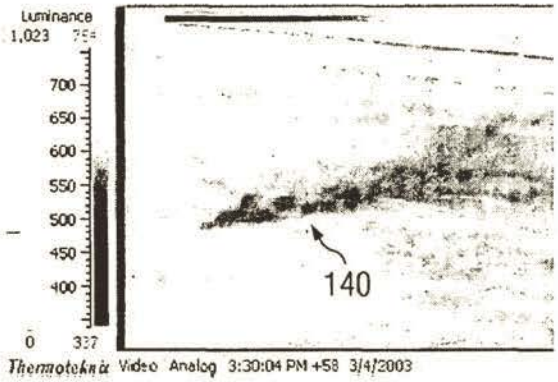

FIG. 23A

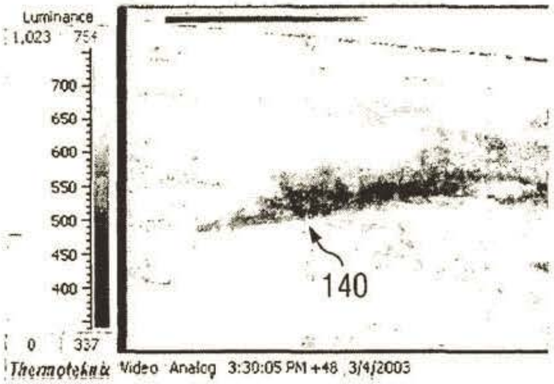

FIG. 23B

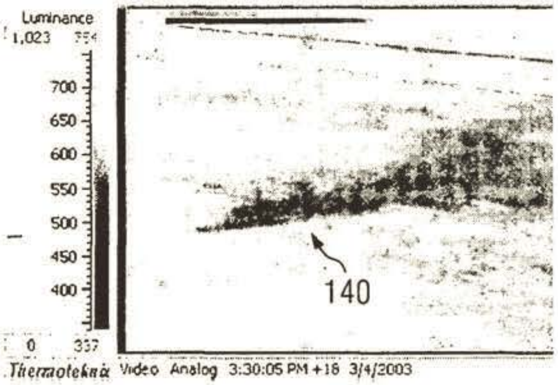

FIG. 23C

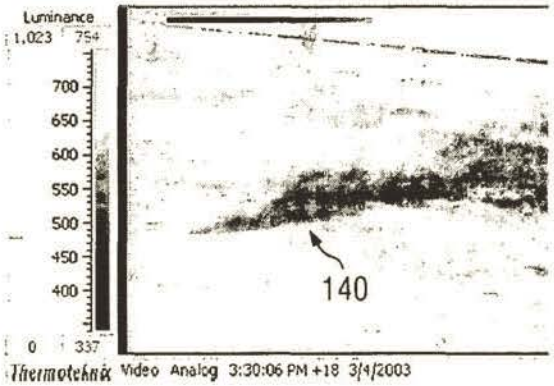

FIG. 23D

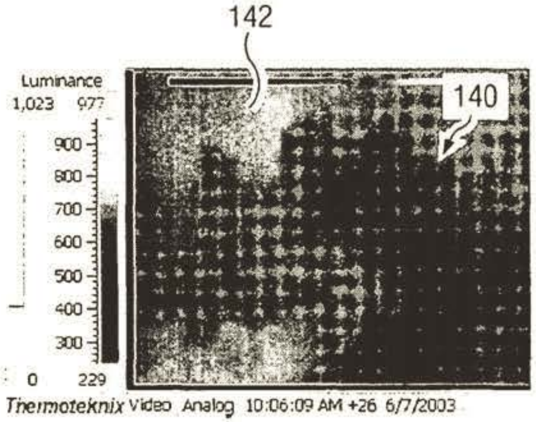

FIG. 24A

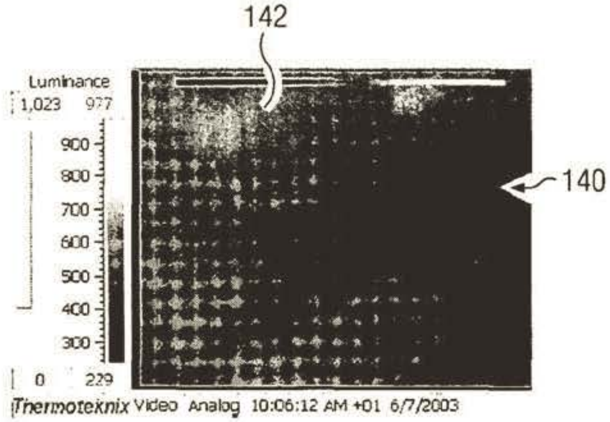

FIG. 24C

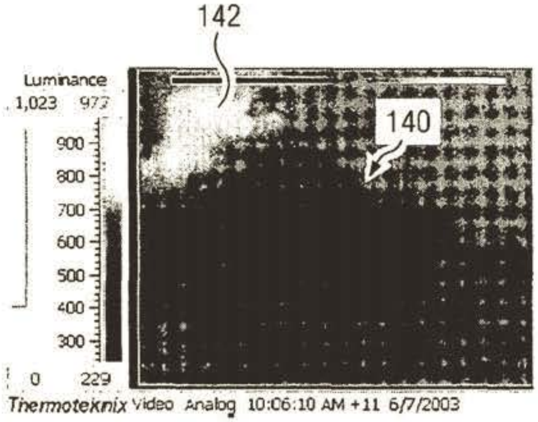

FIG. 24B

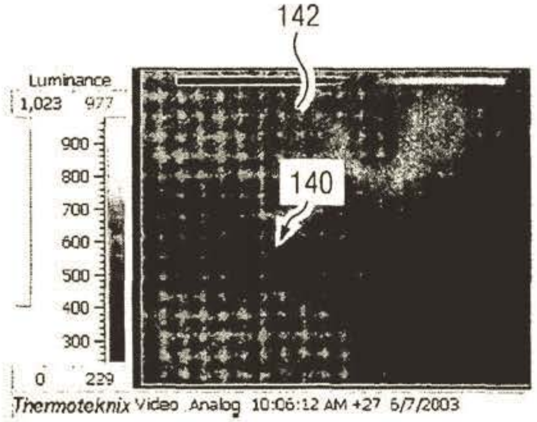

FIG. 24D

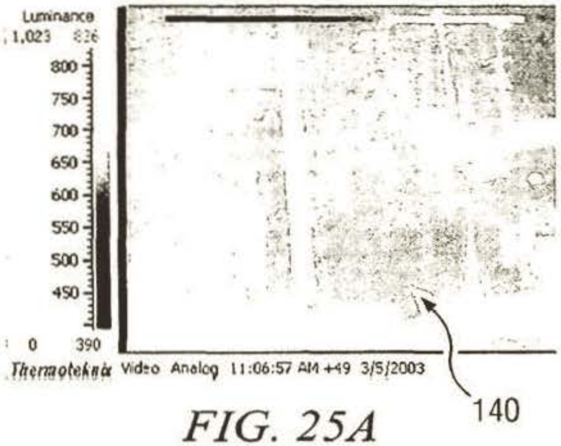

FIG. 25A

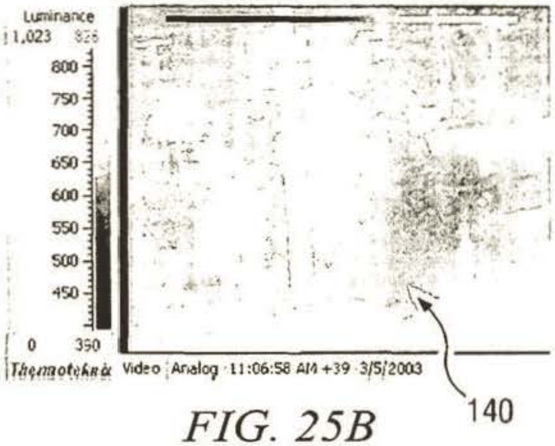

FIG. 25B

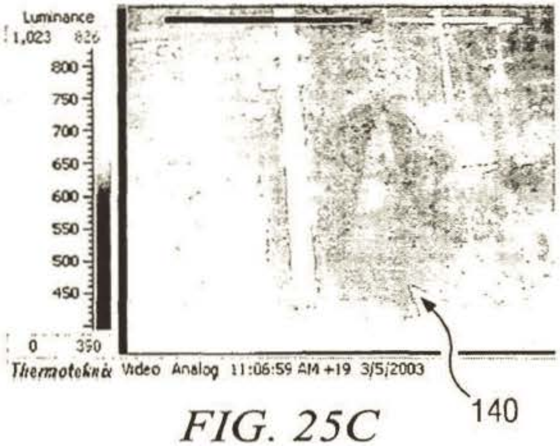

FIG. 25C

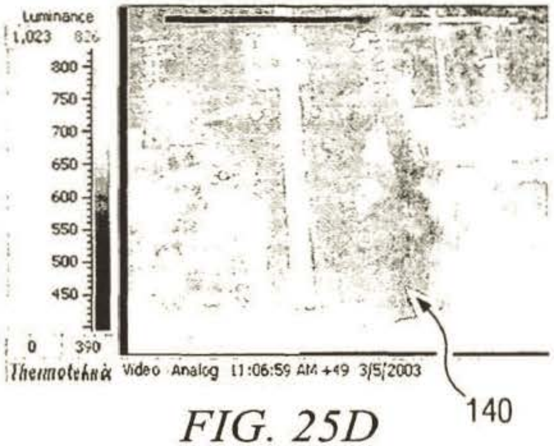

FIG. 25D

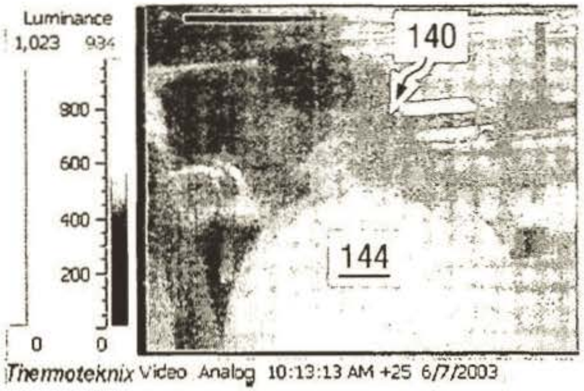

FIG. 26

FIG. 28A

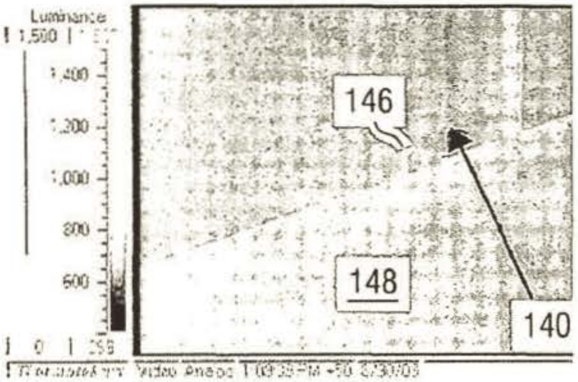

FIG. 27

FIG. 28B

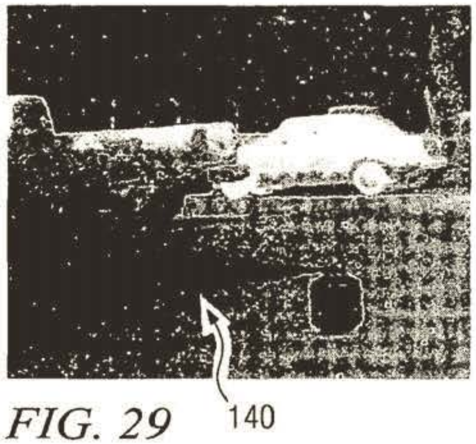

FIG. 29

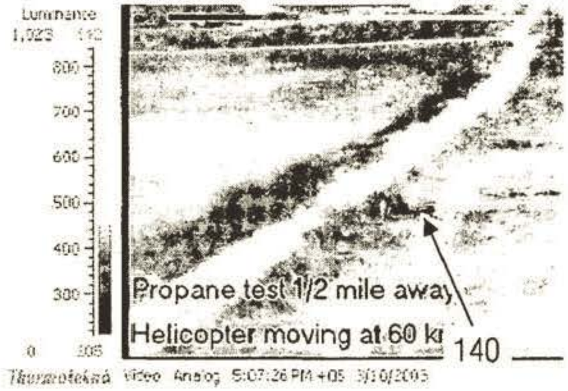

FIG. 31A

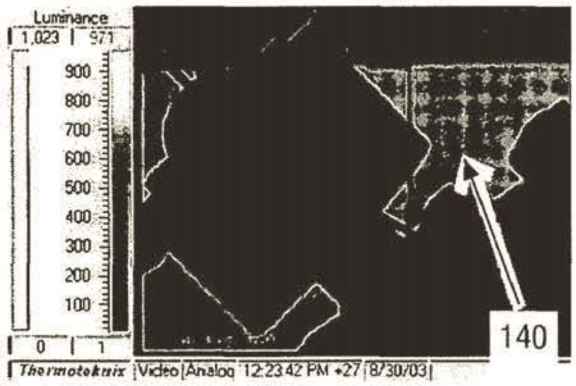

FIG. 30

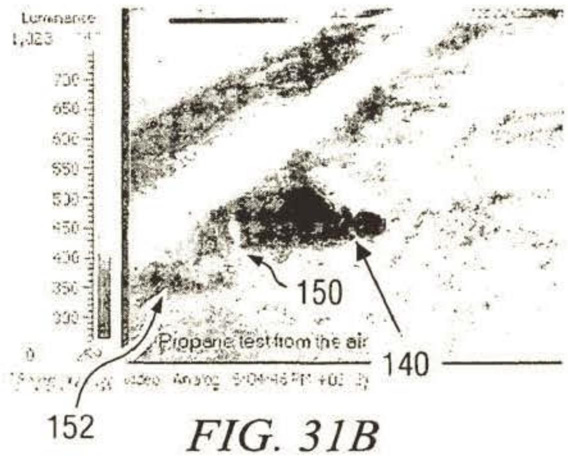

FIG. 31B

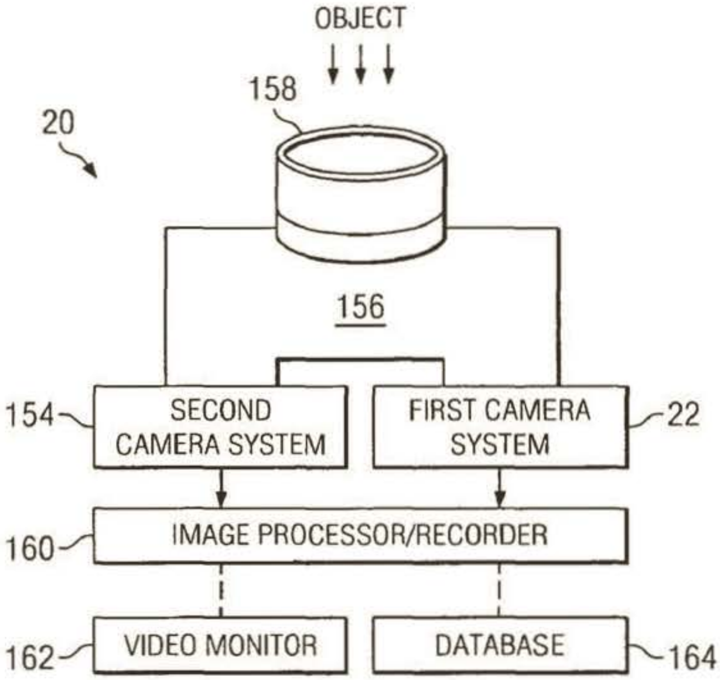
OBJECT
158
20
156
154
SECOND CAMERA SYSTEM
FIRST CAMERA SYSTEM
22
160
IMAGE PROCESSOR/RECORDER
162
VIDEO MONITOR
DATABASE
164

FIG. 32

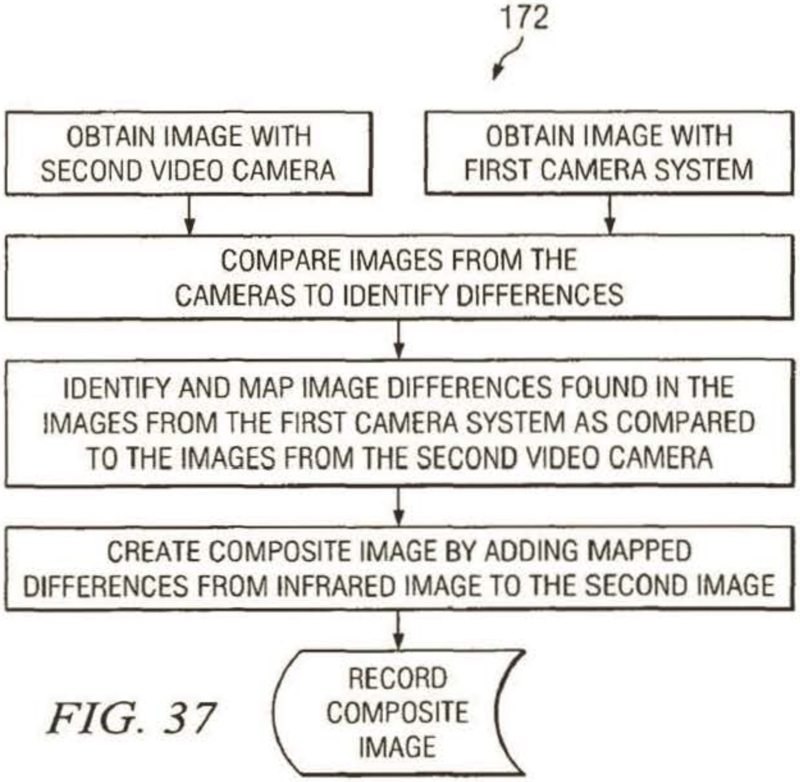
172
OBTAIN IMAGE WITH SECOND VIDEO CAMERA
OBTAIN IMAGE WITH FIRST CAMERA SYSTEM
COMPARE IMAGES FROM THE CAMERAS TO IDENTIFY DIFFERENCES
IDENTIFY AND MAP IMAGE DIFFERENCES FOUND IN THE IMAGES FROM THE FIRST CAMERA SYSTEM AS COMPARED TO THE IMAGES FROM THE SECOND VIDEO CAMERA
CREATE COMPOSITE IMAGE BY ADDING MAPPED DIFFERENCES FROM INFRARED IMAGE TO THE SECOND IMAGE
RECORD COMPOSITE IMAGE

FIG. 37

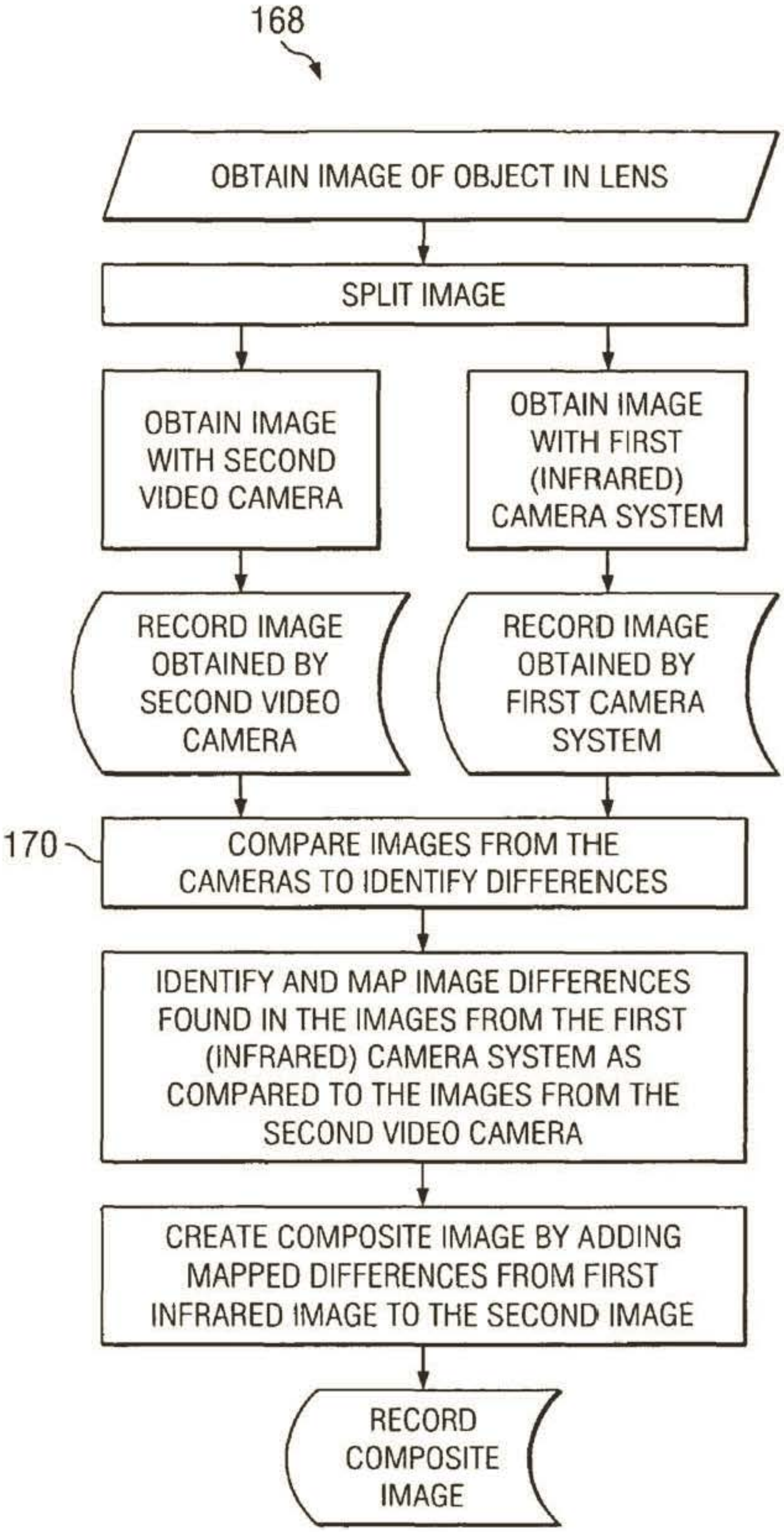
168
OBTAIN IMAGE OF OBJECT IN LENS
SPLIT IMAGE
OBTAIN IMAGE WITH SECOND VIDEO CAMERA
OBTAIN IMAGE WITH FIRST (INFRARED) CAMERA SYSTEM
RECORD IMAGE OBTAINED BY SECOND VIDEO CAMERA
RECORD IMAGE OBTAINED BY FIRST CAMERA SYSTEM
170
COMPARE IMAGES FROM THE CAMERAS TO IDENTIFY DIFFERENCES
IDENTIFY AND MAP IMAGE DIFFERENCES FOUND IN THE IMAGES FROM THE FIRST (INFRARED) CAMERA SYSTEM AS COMPARED TO THE IMAGES FROM THE SECOND VIDEO CAMERA
CREATE COMPOSITE IMAGE BY ADDING MAPPED DIFFERENCES FROM FIRST INFRARED IMAGE TO THE SECOND IMAGE
RECORD COMPOSITE IMAGE

FIG. 33

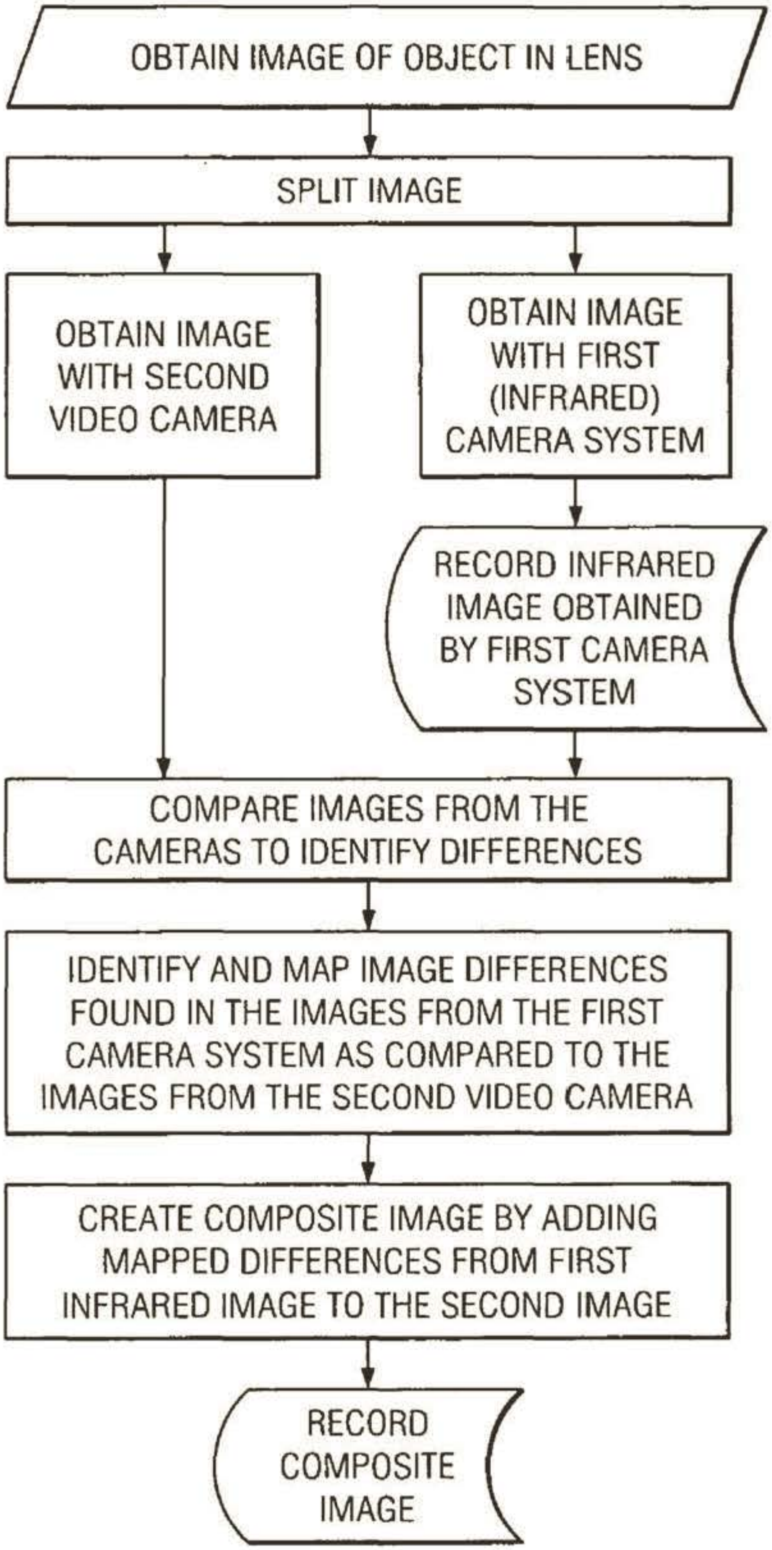
OBTAIN IMAGE OF OBJECT IN LENS
SPLIT IMAGE
OBTAIN IMAGE WITH SECOND VIDEO CAMERA
OBTAIN IMAGE WITH FIRST (INFRARED) CAMERA SYSTEM
RECORD INFRARED IMAGE OBTAINED BY FIRST CAMERA SYSTEM
COMPARE IMAGES FROM THE CAMERAS TO IDENTIFY DIFFERENCES
IDENTIFY AND MAP IMAGE DIFFERENCES FOUND IN THE IMAGES FROM THE FIRST CAMERA SYSTEM AS COMPARED TO THE IMAGES FROM THE SECOND VIDEO CAMERA
CREATE COMPOSITE IMAGE BY ADDING MAPPED DIFFERENCES FROM FIRST INFRARED IMAGE TO THE SECOND IMAGE
RECORD COMPOSITE IMAGE

FIG. 34

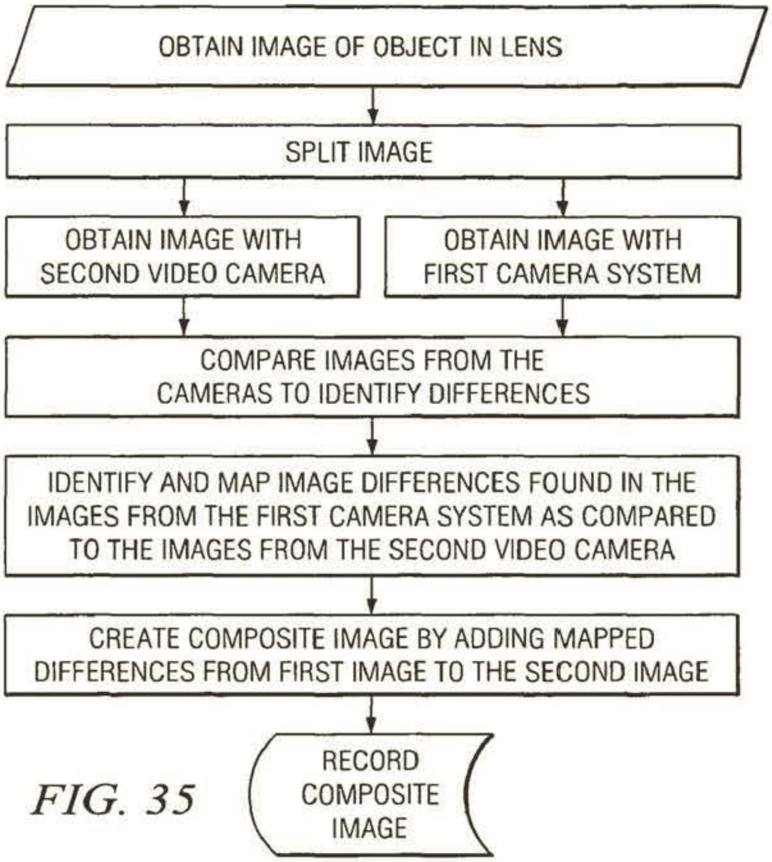
OBTAIN IMAGE OF OBJECT IN LENS
SPLIT IMAGE
OBTAIN IMAGE WITH SECOND VIDEO CAMERA
OBTAIN IMAGE WITH FIRST CAMERA SYSTEM
COMPARE IMAGES FROM THE CAMERAS TO IDENTIFY DIFFERENCES
IDENTIFY AND MAP IMAGE DIFFERENCES FOUND IN THE IMAGES FROM THE FIRST CAMERA SYSTEM AS COMPARED TO THE IMAGES FROM THE SECOND VIDEO CAMERA
CREATE COMPOSITE IMAGE BY ADDING MAPPED DIFFERENCES FROM FIRST IMAGE TO THE SECOND IMAGE
RECORD COMPOSITE IMAGE

FIG. 35

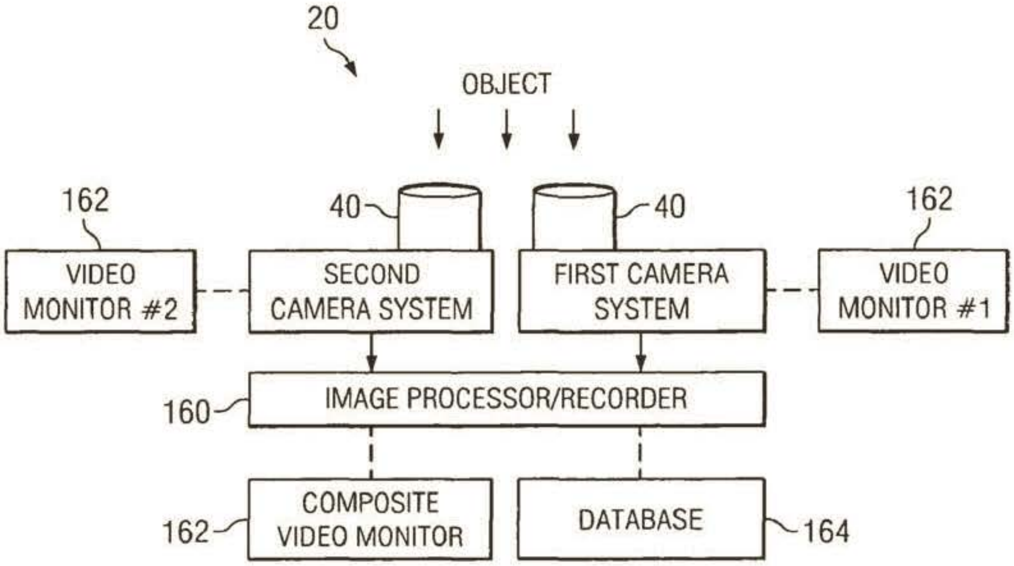
20
OBJECT
162
40
40
162
VIDEO MONITOR #2
SECOND CAMERA SYSTEM
FIRST CAMERA SYSTEM
VIDEO MONITOR #1
160
IMAGE PROCESSOR/RECORDER
162
COMPOSITE VIDEO MONITOR
DATABASE
164

FIG. 36

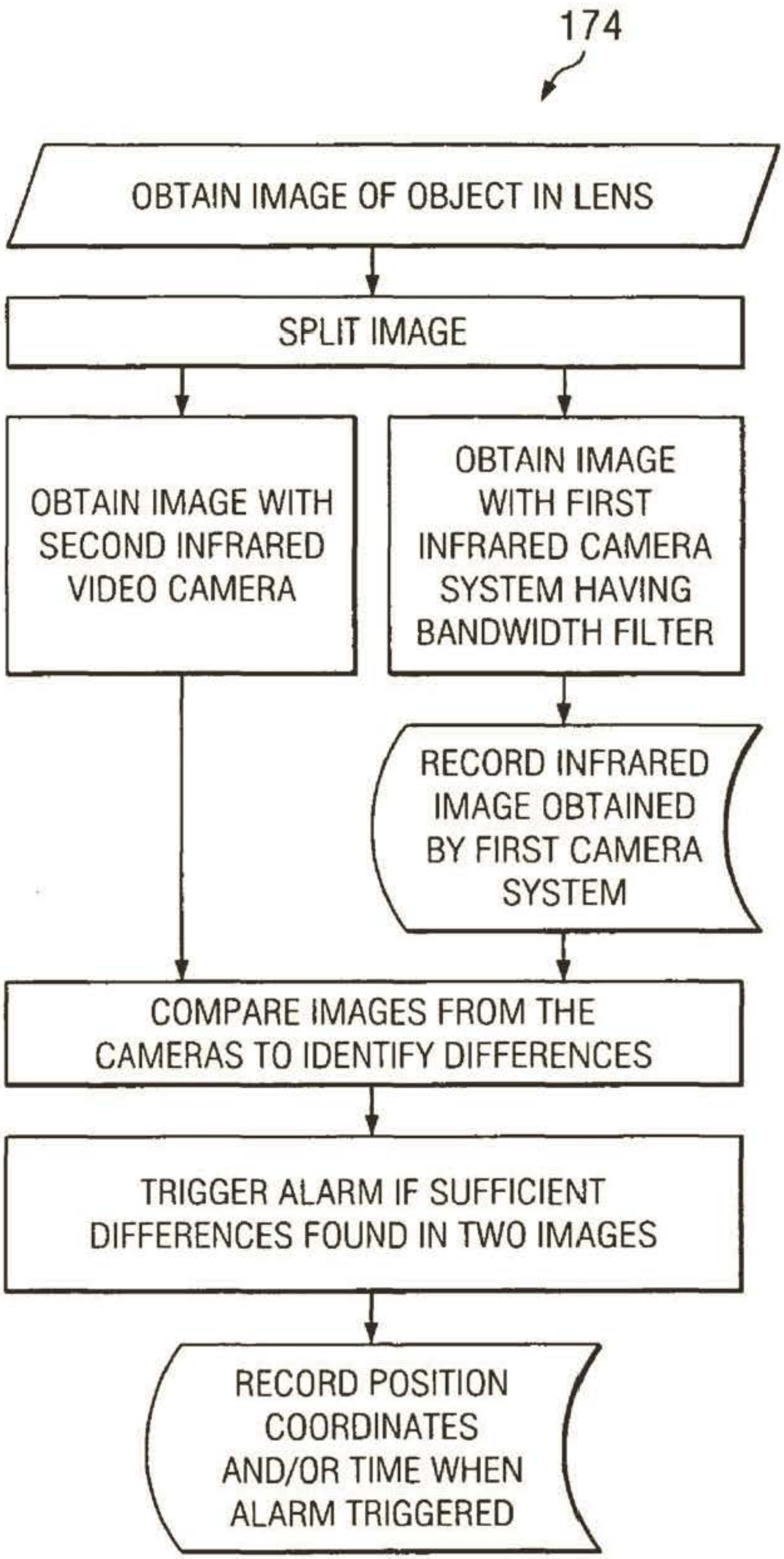
174
OBTAIN IMAGE OF OBJECT IN LENS
SPLIT IMAGE
OBTAIN IMAGE WITH SECOND INFRARED VIDEO CAMERA
OBTAIN IMAGE WITH FIRST INFRARED CAMERA SYSTEM HAVING BANDWIDTH FILTER
RECORD INFRARED IMAGE OBTAINED BY FIRST CAMERA SYSTEM
COMPARE IMAGES FROM THE CAMERAS TO IDENTIFY DIFFERENCES
TRIGGER ALARM IF SUFFICIENT DIFFERENCES FOUND IN TWO IMAGES
RECORD POSITION COORDINATES AND/OR TIME WHEN ALARM TRIGGERED

FIG. 38

METHODS FOR PERFORMING INSPECTIONS AND DETECTING CHEMICAL LEAKS USING AN INFRARED CAMERA SYSTEM

This application is a continuation of PCT International Application No. PCT/2004/012946, WO2005/001409 A2, filed on Apr. 26, 2004, entitled SYSTEMS AND METHODS FOR PERFORMING INSPECTIONS AND DETECTING CHEMICAL LEAKS USING AN INFRARED CAMERA SYSTEM, which claims the benefit of U.S. Provisional Application No. 60/477,994, filed on Jun. 11, 2003, entitled METHOD OF DETECTING GAS LEAKS USING AN INFRARED CAMERA SYSTEM, and U.S. Provisional Application No. 60/482,070, filed on Jun. 23, 2003, entitled METHOD OF DETECTING GAS LEAKS USING AN INFRARED CAMERA SYSTEM, and U.S. Provisional Application No. 60/540,679, filed on Jan. 30, 2004, entitled METHOD OF DETECTING GAS LEAKS USING AN INFRARED CAMERA SYSTEM, all of which application are hereby incorporated herein by reference.

TECHNICAL FIELD

The present invention relates generally to visually detecting and identifying chemical, gas, and petroleum product leaks using an infrared (IR) camera system.

BACKGROUND

In the oil and gas business, in the petrochemical industry, in processing plants, and for utility companies and utility providers, for example, often more time and money is spent trying to find leaks than fixing leaks. One of the biggest challenges is trying to find the leaks using conventional methods. Many conventional methods can simply miss a leak and not detect it if the detector is not properly positioned over or downwind of the leak. Also, many conventional methods are very time consuming and labor intensive, which leads to more expense. Hence, there is a great need for a faster, more accurate, and less expensive method of detecting such leaks.

Petroleum products, such as liquid, gas, and liquid/gas forms of hydrocarbon compounds (e.g., fossil fuels), are often transmitted or channeled in pipes. The conventional method of surveying lines for petroleum product leaks or for detecting petroleum product leaks in general is with a flame-pack ionizer detector (also sometimes referred to as a "sniffer" device). Another recently developed system uses an active infrared system (having a transmitting infrared source and a receiving sensor) for detecting petroleum product fumes. However, such systems require that the detector be within the stream or plume of the petroleum product leak. These tests merely detect the presence of petroleum product fumes at or upwind of the detector. They do not provide a visual image of the leak. Also, these prior testing methods require the detector to be in the immediate proximity of the leak, which may be dangerous and/or difficult for the inspector.

Prior infrared systems designed for evaluating rocket fumes, for example, would provide an unfocused and fuzzy image, in which it was difficult to make out background objects. For example, using an infrared camera that images a broad range of infrared wavelengths (e.g., 3-5 microns) typically will not be useful in detecting small leaks. One system uses a variable filter that scans through different bandwidths in an attempt to identify the bandwidth of the strongest intensity (as quantified by the system). The purpose of this system

was an attempt to identify the chemical make-up of a rocket exhaust based on the wavelength at which the intensity was greatest for the rocket plume. However, this system is not designed to provide a focused visual image to view the rocket exhaust.

Others have attempted to visualize petroleum product leaks using infrared cameras using a "warm" filter setup and/or an active infrared camera system. A warm filter setup is one in which a filter is used to limit the wavelengths of light that reach the infrared sensor, but the filter is not in a cooled or refrigerated portion of the camera, if the camera even has a refrigerated portion. Such systems have not been able to provide a focused image capable of quickly and easily detecting small leaks, nor being capable of detecting leaks from a distance (e.g., from a helicopter passing over a line). Other systems are active and require a laser beam to be projected through the area under inspection in order to detect the presence of a chemical emanating from a component. However, with such systems, typically the narrow laser beam must cross the flow stream for the leak to be detected. Hence, a leak may be missed if the laser beam does not cross the path of the leak and such systems often are unable to reliably find small leaks. Hence, a need exists for a way to perform a visual inspection to find leaks with reliability and accuracy, while being faster and more cost effective than existing leak survey methods.

The U.S. Environmental Protection Agency (EPA) has proposed rules to allow visual inspections using infrared cameras in performing leak inspection surveys. However, due to the lack of detection abilities and poor performance demonstrated by other prior and current systems, the EPA had not yet implemented such rules. Thus, even the EPA has been waiting for someone to provide a system or way of reliably and accurately detecting leaks of various sizes.

SUMMARY OF THE INVENTION

The problems and needs outlined above may be addressed by embodiments of the present invention. In accordance with one aspect of the present invention, a passive infrared camera system adapted to provide a visual image of a chemical emanating from a component having the chemical therein, is provided. The passive infrared camera system includes a lens, a refrigerated portion, and a refrigeration system. The refrigerated portion has therein an infrared sensor device and an optical bandpass filter. The infrared sensor device is adapted to capture an infrared image from the lens. The optical bandpass filter is located along an optical path between the lens and the infrared sensor device. At least part of a pass band for the optical bandpass filter is within an absorption band for the chemical. The refrigeration system is adapted to cool the refrigerated portion of the infrared camera system.

In accordance with another aspect of the present invention, a method of visually detecting a leak of a chemical emanating from a component, is provided. This method includes the following steps described in this paragraph. The order of the steps may vary, may be sequential, may overlap, may be in parallel, and combinations thereof. A passive infrared camera system is aimed towards the component. The passive infrared camera system includes a lens, a refrigerated portion, and a refrigeration system. The refrigerated portion includes therein an infrared sensor device and an optical bandpass filter. The optical bandpass filter is located along an optical path between the lens and the infrared sensor device. At least part of a pass band for the optical bandpass filter is within an absorption band for the chemical. The refrigeration system is adapted to cool the refrigerated portion. An infrared image is filtered with the optical bandpass filter. The infrared image is that of the leak of the chemical emanating from the component. After the infrared image passes through the lens and optical bandpass filter, the filtered infrared image of the leak is received with the infrared sensor device. The filtered infrared image received by the infrared sensor device is electronically processed to provide a visible image representing the filtered infrared image. The leak is visually identified based on the visible image representing the filtered infrared image provided by the infrared camera system.

The foregoing has outlined rather broadly features of the present invention in order that the detailed description of the invention that follows may be better understood. Additional features and advantages of the invention will be described hereinafter which form the subject of the claims of the invention. It should be appreciated by those skilled in the art that the conception and specific embodiment disclosed may be readily utilized as a basis for modifying or designing other structures or processes for carrying out the same purposes of the present invention. It should also be realized by those skilled in the art that such equivalent constructions do not depart from the spirit and scope of the invention as set forth in the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

The following is a brief description of the drawings, which illustrate exemplary embodiments of the present invention and in which:

FIG. **1** is perspective view of a chemical leak detection system of a first embodiment;

FIG. **2** is a schematic of the infrared camera system of the chemical leak detection system of FIG. **1**;

FIGS. **3**A-**3**D are absorption graphs for methane;

FIG. **4** is a transmission curve illustrating a pass band of an optical bandpass filter;

FIG. **5** is an absorption graph for a small set of alkane chemicals with the pass band of the first embodiment transposed thereon;

FIG. **6** is an absorption graph for a small set of alkene chemicals with the pass band of the first embodiment transposed thereon;

FIG. **7** is an absorption graph for a small set of aromatic chemicals with the pass band of the first embodiment transposed thereon;

FIG. **8** is an absorption graph for a small set of alkane chemicals with a schematic representation of a pass band for a second embodiment transposed thereon;

FIG. **9** is an absorption graph for a small set of alkene chemicals with a schematic representation of a pass band for a third embodiment transposed thereon;

FIG. **10** is an absorption graph for a small set of aromatic chemicals with a schematic representation of a pass band for a fourth embodiment transposed thereon;

FIG. **11** is an absorption graph for methane with a schematic representation of a pass band for a fifth embodiment transposed thereon;

FIG. **12** is an absorption graph for methane with a schematic representation of a pass band for a sixth embodiment transposed thereon;

FIG. **13** is an absorption graph for ethylene with a schematic representation of a pass band for a seventh embodiment transposed thereon;

FIG. **14** is an absorption graph for ethylene with a schematic representation of a pass band for an eighth embodiment transposed thereon;

FIG. **15** is an absorption graph for propylene with a schematic representation of a pass band for a ninth embodiment transposed thereon;

FIG. **16** is an absorption graph for propylene with a schematic representation of a pass band for a tenth embodiment transposed thereon;

FIG. **17** is an absorption graph for 1,3 butadiene with a schematic representation of a pass band for an eleventh embodiment transposed thereon;

FIG. **18** is an absorption graph for 1,3 butadiene with a schematic representation of a pass band for a twelfth embodiment transposed thereon;

FIG. **19** is an absorption graph for sulfur hexafluorine with a schematic representation of a pass band for a thirteenth embodiment transposed thereon;

FIG. **20** is perspective view of a chemical leak detection system of a fourteenth embodiment;

FIG. **21** shows an inspector using an embodiment of the present invention;

FIG. **22** illustrates a use of an embodiment of the present invention to inspect multiple yards from a single yard;

FIGS. **23**A-**31**B are example images obtained using an embodiment of the present invention;

FIG. **32** is a schematic of a dual camera embodiment of the present invention;

FIGS. **33**-**35** are flowcharts illustrating methods of using a dual camera embodiment of the present invention;

FIG. **36** is a schematic of another dual camera embodiment of the present invention; and

FIGS. **37** and **38** are flowcharts illustrating more methods of using a dual camera embodiment of the present invention.

DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

Referring now to the drawings, wherein like reference numbers are used herein to designate like or similar elements throughout the various views, illustrative embodiments of the present invention are shown and described. The figures are not necessarily drawn to scale, and in some instances the drawings have been exaggerated and/or simplified in places for illustrative purposes only. One of ordinary skill in the art will appreciate the many possible applications and variations of the present invention based on the following illustrative embodiments of the present invention.

FIG. **1** shows a chemical leak inspection system **20** in accordance with a first embodiment of the present invention. The chemical leak inspection system **20** of the first embodiment includes a passive infrared camera system **22**. The passive infrared camera system **22** of the first embodiment is adapted to provide a visible image representing a filtered infrared image of a chemical emanating (e.g., leaking) from a component having the chemical therein, as discussed in more detail below.

As shown in FIG. **1**, the infrared camera system **22** may be mounted on a frame **24**. A shoulder-rest portion **26** and handles **28** may be attached to the frame **24**, as shown in FIG. **1**. The shoulder-rest portion **26** and the handles **28** aid in holding the system **20** during an inspection (see e.g., FIG. **21** discussed below). Typically during an inspection using this system **20**, an inspector will walk around various components while carrying the system **20** on his shoulder and aiming the system **20** toward the components to look for leaks. In other embodiments, however, the camera system **22** may be handled or carried in other ways (e.g., by hand, from a vehicle, on a vehicle, on a tripod, on a gyro-stabilized platform, by a harness, etc.). Also, as discussed further below, inspections using an embodiment of the present invention may be performed from a vehicle (moving and not moving).

The leak inspection system **20** of the first embodiment also has a flat-panel display screen **30** (e.g., LCD display) electrically coupled to the infrared camera system **22** (see e.g., FIG. **1**). The visible images (representing the filtered infrared images) provided by the camera system **22** may be displayed on the display screen **30** during an inspection. The system **20** preferably includes a video recording device **32** (not shown in FIG. **1**, but see, e.g., FIG. **21** discussed below) electrically coupled to the camera system **22** for recording images obtained by the camera system **22** during use of the system **20**. The video recording device **32** may be attached to the frame **24** or it may be carried separately by the inspector (e.g., in a backpack or in a carrying case **34** as shown in FIG. **21**), for example. The video recording device **32** may record the images in a digital and/or analog format, for example. Thus, during use of the system **20** for locating a leak, an inspector may find a leak visually, as viewed on the display screen **30**, and then record detailed and focused images of the leak using the video recording device **32** for future observation and/or for obtaining a record of the leak.

The system **20** of the first embodiment has a battery **36** electrically coupled to the infrared camera system **22**. Preferably, the system **20** is powered by the battery **36** during use of the system **20** to allow the inspector to move about freely during an inspection. In other embodiments, however, the system **20** may be powered via a power cord by electricity from a wall outlet, from a generator, or from an alternator of a vehicle, for example. Typically, it will be less preferable to power the system **20** via a power cord, as it may limit the mobility of the inspector and/or slow down the inspection process.

FIG. **2** is a schematic of the infrared camera system **22** of FIG. **1** to illustrate some of the components therein. In the first embodiment, the passive infrared camera system **22** has one or more lenses **38** in a lens assembly **40** for optically focusing the image. Preferably, the lens assembly **40** is removable to allow for different lens assemblies (e.g., with different focal ranges) to be removably installed on the camera system **22**. The camera system **22** has a refrigerated portion **42** that comprises therein an infrared sensor device **44** and an optical bandpass filter **46**. The refrigerated portion **42** is preferably defined by an interior of a dewar container **48**. Preferably, the dewar container **48** has an evacuated region **50** surrounding the refrigerated portion **42** to provide insulation. The dewar container **48** may be made from metal and it has at least one dewar window **52** for allowing the infrared image from the lens assembly **40** to enter into the refrigerated portion **42**. The infrared sensor device **44**, located in the refrigerated portion **42**, is adapted to capture infrared images that come into the refrigerated portion **42** via the lens assembly **40**. In a preferred embodiment, the infrared sensor device **44** is a focal plane array (FPA) of Indium Antimonide (InSb) sensors (e.g., a 320×256 matrix) to provide a high sensitivity in the 3-5 micron range of infrared light, for example. Other materials may be used for the infrared sensor device **44** in other embodiments to provide high sensitivity to other wavelength ranges of infrared light. The infrared sensor device **44** is electrically coupled to other electronic components (represented generally by block **54** in FIG. **2**), which may be inside and/or outside of the camera system **22**. The design of the infrared sensor device **44** and the electronic components **54** for the camera system **22** may vary for other embodiments of the present invention.

The refrigerated portion **42** is cooled by a refrigeration system **60**. The refrigeration system **60** used may vary for different embodiments of the present invention. Preferably, the refrigeration system **60** is capable of maintaining the temperature in the refrigerated portion **42** below about 100 K (i.e., less than about −173° C.). More preferably, the temperature in the refrigerated portion **42** is maintained between about 75 K and about 85 K by the refrigeration system **60**. In the first embodiment, the refrigeration system **60** includes a closed-cycle Stirling cryocooler, as illustrated schematically in FIG. **2**. The actual configuration of the Stirling cycle cryocooler **60** for a given embodiment may vary from that shown in FIG. **2**. A cold finger **62** may be used to provide a thermal communication between the refrigerated portion **42** and a regenerator cylinder **64**, as shown in FIG. **2**. The Stirling cycle cryocooler **60** may use helium as a refrigerant or cryogenic fluid, for example. In a preferred embodiment, a closed-cycle Stirling cryocooler **60** may be used to thermally stabilize the temperature in the refrigerated portion **42** at about 77 K, for example. A preferred infrared camera system **22**, for example, for use in an embodiment of the present invention is a Merlin™ mid-wavelength infrared (MWIR) high-performance camera available from Indigo Systems, Inc. in California.

As illustrated schematically in FIG. **2**, the optical bandpass filter **46** is located along an optical path between the lens assembly **40** and the infrared sensor device **44**, and hence infrared images are filtered by the optical bandpass filter **46** before reaching the infrared sensor device **44**. The optical bandpass filter **46** of the first embodiment has a pass band (bandpass transmittance range) located between about 3100 nm and about 3600 nm. Because the optical bandpass filter **46** is cooled, i.e., located in the refrigerated portion **42**, in the first embodiment, the filter **46** works better than if it were not cooled (e.g., not in the refrigerated portion **42**), and it allows for a more focused image than if a warm (uncooled) optical bandpass filter configuration were used. In a preferred embodiment, the optical bandpass filter **46** is cooled to a temperature below about 100 K. Cooling the optical bandpass filter **46** in the refrigerated portion **42** (i.e., "cold" filter configuration) provides a greater temperature contrast (greater temperature differential) between the leaking chemical and the optical bandpass filter **46**, which increases the sensitivity of the camera system **22** for imaging the leaking chemical. Cooling the optical bandpass filter **46** effectively reduces the background noise of the filter **46** (as perceived by the infrared sensor device **44**). When the optical bandpass filter **46** is not cooled (i.e., "warm" filter configuration), the level of background noise produced by the filter itself is much higher (relative to a cold filter configuration) and thus the sensitivity to detecting the infrared light absorbed by the leaking chemical after the infrared image passes through the warm filter is reduced. Also, in a warm filter configuration, the temperature difference between the optical bandpass filter and the leaking chemical is much smaller than that of a "cold" filter.

The camera system **22** of FIGS. **1** and **2**, of the first embodiment, is a passive infrared camera system. Hence, the camera system **22** relies on the background (whatever the background may be) to be a reflector of environmental light and heat to the camera system **22**. Most chemicals of interest have one or more absorbance bands (wavelength ranges where the absorbance of infrared light is orders of magnitude higher). For example, FIGS. **3A-3D** show absorbance graphs for methane (CH4) gas based on experimental data.

In each graph of FIGS. **3A-3D**, the vertical axis is absorbance (unitless) and the horizontal axis is wavelength (μm) of infrared light. Transmission and absorbance are inversely related. Transmission is typically defined as the fraction of light that reaches a detector after passing through a sample (e.g., an optical filter, a gas):

$$T=I/Io \text{ or } \%T=100(I/Io),$$

where I denotes light intensity reaching the detector after passing through a sample, Io denotes light intensity of a reference beam or source beam with no sample present, T denotes transmission (expressed as a fraction), and % T denotes transmission (expressed as a percentage). Absorbance is a logarithmic scale that increases as transmission decreases:

$$A=\log 10(Io/I),$$

where A denotes absorbance. Infrared radiation is often measured in units of wavelength (e.g., microns or nanometers). Also, infrared radiation is sometimes measured in units called wavenumbers (cm−1):

$$\text{wavenumber (cm−1)}=107/\lambda=E/hc\times 1/100,$$

where λ is wavelength in nanometers, E is energy (J), h is Planck's constant (6.626×10−34 J s), and c is the speed of light (3.0×108 m/s). Hence, the wavenumber of a light wave is directly proportional to its wavelength and its energy.

FIG. **3**A shows the absorbance of methane from about 1.5 μmto about 16.5 μm (infrared light). Note that for methane, there are two major absorbance bands **71**, **72** where the absorbance of infrared light is much higher (orders of magnitude higher) than at other adjacent wavelengths. A first absorbance band **71** is located between about 3.1 μm and about 3.6 μm, and a second absorbance band **72** is located between about 7.2 μm and about 8.2 μm (see FIG. **3**A). FIG. **3**B shows a range of wavelengths between about 3.15 μm and about 3.45 μm to illustrate the first absorbance band **71** of FIG. **3**A in more detail. Note that the vertical scale for the graph in FIG. **3**A is the same as that of FIG. **3**B. FIG. **3**C shows a range of wavelengths between about 7.2 μm and about 8.2 μm to illustrate the second absorbance band **72** of FIG. **3**A in more detail. Note that the vertical scale of the graph in FIG. **3**C is orders of magnitude smaller than that of FIG. **3**A. There are also other absorbance bands (**73**) for methane in the range shown in FIG. **3**A, but they have orders of magnitude less absorbance than the first and second absorbance bands **71**, **72**. For example, a third absorbance band **73** is shown in FIG. **3**A at about 2.3 μm. FIG. **3**D shows a range of wavelengths between about 2.15 μm and about 2.45 μm to illustrate the third absorbance band **73** in more detail. The vertical scale for the graph in FIG. **3**D is orders of magnitude smaller than that of FIG. **3**A-**3**C. Hence, methane has a much higher absorbance of infrared light between about 3.1 μm and about 3.5 μm (overlapping or within the first absorption band **71**). Thus, an infrared camera system **22** adapted to detect infrared light between about 3-5 μm, for example, will have high sensitivity for imaging methane between about 3.1 μm and about 3.5 μm. The absorbance of methane at the second absorbance band **72** (see FIG. **3**A) may be easily detected as well by an infrared camera system **22** adapted to detect infrared light at that range (e.g., about 7-8 μm).

In a preferred embodiment of the present invention adapted to visually detect a certain chemical (and perhaps other chemicals as well) leaking from a component, the optical bandpass filter **46** is located in the refrigerated portion **42** of the infrared camera system **22** and the optical bandpass filter **46** has a pass band that is at least partially located in an absorption band for the chemical. For example, in the first embodiment, the optical bandpass filter **46** has a pass band **80** located between 3200 nm and 3550, as illustrated by the transmission curve for the filter **46** in FIG. **4**. The first embodiment is adapted to visually detect methane, for example, (as well as other chemicals). As discussed above, methane has a first absorption band **71** (see FIGS. **3**A and **3**B) located between about 3100 nm and about 3500 nm.

The optical bandpass filter **46** of the first embodiment has a full width at half maximum (HW) **82** of about 64.4 nm, a center wavelength **84** of about 3382 nm, and a peak transmission **86** of about 91.16%, as shown in transmission curve of FIG. **4**. The optical bandpass filter **46** of the first embodiment is a single bandpass passive filter formed on a quartz (SiO2) substrate, which is currently preferred. A preferred bandpass filter providing such performance characteristics may be obtained from Spectrogon US, Inc. in New Jersey, for example. Other optical bandpass filters of other embodiments may have different transmission curves with different pass bands, different shapes, different materials, and different characteristics (e.g., full width at half maximum **82**, center wavelength **84**, peak transmission **86**, etc.). There are many different optical bandpass filters available from numerous manufacturers. Referring to FIG. **4**, the optical bandpass filter **46** of the first embodiment allows a transmittance greater than about 45% for infrared light between about 3360 nm and about 3400 nm to pass therethrough. Another optical bandpass filter (curve not shown) may be used in alternative, for example, that allows a transmittance greater than about 45% for infrared light between about 3350 nm and about 3390 nm to pass therethrough, which may provide similar or essentially the same results as the filter of the first embodiment.

FIG. **5** is a graph between 3000 nm and 3600 nm showing absorption bands for some common alkane chemicals: methane (**71**), ethane (**88**), propane (**90**), butane (**92**), and hexane (**94**), for example. In FIG. **5**, the pass band **80** for the filter **46** of the first embodiment has been overlaid with the absorption bands **71**, **88**, **90**, **92**, **94**. In FIG. **5**, note that at least part of the pass band **80** for the optical bandpass filter **46** is located within the first absorption band **71** for methane. The use of this optical bandpass filter **46** in the first embodiment provides a high sensitivity to infrared light being absorbed by methane between about 3200 nm and about 3500 nm (see FIG. **5**). Also, note that the pass band **80** for this optical bandpass filter **46** also provides a high sensitivity to infrared light being absorbed by ethane (**88**), propane (**90**), butane (**92**), and hexane (**94**) between about 3200 nm and about 3500 nm (see FIG. **5**). Although an embodiment may be adapted to detect a certain chemical leaking from a component, the same set up may also be useful and capable of detecting a set or group of chemicals, as is the case for the first embodiment of the present invention. Thus, the infrared camera system **22** of the first embodiment is adapted to provide a visible image representing an infrared image of methane, ethane, propane, butane, and/or hexane emanating from a component.

FIG. **6** is a graph between 3000 nm and 3600 nm showing absorption bands for some common alkene chemicals: propylene (**96**) and ethylene (**98**), for example. In FIG. **6** (as in FIG. **5**), the pass band **80** for the filter **46** of the first embodiment has been overlaid with the absorption bands of propylene (**96**) and ethylene (**98**) located between 3000 nm and 3600 nm. In FIG. **6**, note that at least part of the pass band **80** for the optical bandpass filter **46** is located within the absorption bands **96**, **98** shown for propylene and ethylene. Thus, the infrared camera system **22** of the first embodiment is also adapted to provide a visible image representing an infrared image of propylene and/or ethylene emanating from a component.

FIG. **7** is a graph between 3000 nm and 3600 nm showing absorption bands for some common aromatic chemicals:

o-xylene (**100**), toluene (**102**), and benzene (**104**), for example. In FIG. **7** (as in FIGS. **5** and **6**), the pass band **80** for the filter **46** of the first embodiment has been overlaid with the absorption bands of o-xylene (**100**), toluene (**102**), and benzene (**104**) located between 3000 nm and 3600 nm. In FIG. **7**, note that at least part of the pass band **80** for the optical pass band filter **46** is located within the absorption bands **100**, **102**, **104** shown for o-xylene, toluene, and benzene. Thus, the infrared camera system **22** of the first embodiment is also adapted to provide a visible image representing an infrared image of o-xylene, toluene, and/or benzene emanating from a component.

In other embodiments adapted to visually detect a methane gas leak emanating from a component (and/or some other chemical having an absorption band overlapping or near that of the first absorption band **71** for methane), the optical bandpass filter **46** may have any of a variety of characteristics, including (but not limited to): the pass band of the optical bandpass filter having a center wavelength located between about 3375 nm and about 3385 nm; the optical bandpass filter being adapted to allow a transmittance greater than about 80% of infrared light between about 3365 nm and about 3395 nm to pass therethrough; the pass band of the optical bandpass filter having a center wavelength located between about 3340 nm and about 3440 nm; the pass band of the optical bandpass filter having a center wavelength between about 3360 nm and about 3380 nm; the pass band for the optical bandpass filter being located between about 3100 nm and about 3600 nm; the pass band for the optical bandpass filter being located between about 3200 nm and about 3500 nm; the pass band for the optical bandpass filter being located between about 3300 nm and about 3500 nm; the pass band of the optical bandpass filter having a full width at half maximum transmittance that is less than about 600 nm; the pass band of the optical bandpass filter having a full width at half maximum transmittance that is less than about 400 nm; the pass band of the optical bandpass filter having a full width at half maximum transmittance that is less than about 200 nm; the pass band of the optical bandpass filter having a full width at half maximum transmittance that is less than about 100 nm; the pass band of the optical bandpass filter having a full width at half maximum transmittance that is less than about 80 nm; the optical bandpass filter being adapted to allow a transmittance greater than about 70% at the center wavelength; the pass band for the optical bandpass filter having a center wavelength located within the absorbance band for the chemical; the pass band for the optical bandpass filter having a center wavelength located partially outside of the absorbance band for the chemical; and combinations thereof, for example.

In other embodiments, the optical bandpass filter **46** may comprise two or more optical filters (e.g., in series) located in the refrigerated portion **42** (i.e., cooled filters) to provide the same function as one single bandpass passive filter. For example, a first optical filter (not shown) of the optical bandpass filter **46** may have a high pass filter characteristic to allow infrared light greater than about 3100 nm to pass therethrough, and a second optical filter (not shown) of the optical bandpass filter **46** may have a low pass filter characteristic to allow infrared light less than about 3600 nm to pass therethrough, which together provide an effective pass band located between about 3100 nm and 3600 nm.

An embodiment of the present invention may be adapted to visually detect a leak of any of a wide variety of chemicals (or evaporated gases therefrom), including (but not limited to): hydrocarbon; methane; ethane; propane; butane; hexane; ethylene; propylene; acetylene; alcohol; ethanol; methanol; xylene; benzene; formaldehyde; 1,2 butadiene; 1,3 butadiene; butadiyne; acetone; gasoline; diesel fuel; petroleum; petrochemicals; petroleum by-product; volatile organic compound; volatile inorganic compound; crude oil products; crude oil by-products; and combinations thereof, for example. FIGS. **8-19** illustrate some example absorption bands (among many) for some example chemicals (among many) that may be detected while leaking from a component using an embodiment of the present invention, and some example pass bands (among many) for the optical bandpass filter **46** that may be used in an embodiment of the present invention.

In FIGS. **8-19**, the pass band **80** for the optical bandpass filter **46** is schematically represented by a rectangular box to show its approximate placement relative to the absorption bands of the chemicals. As is well known by those of ordinary skill in the art, the actual pass band for an optical bandpass filter will typically have some sort of curve shape (often a bell-curve shape) rather than being rectangular. The rectangular shape is merely used for schematic illustration, as the actual pass band (and the actual transmission curve) for an optical bandpass filter **46** of an embodiment may have any of a wide variety of shapes (symmetry, asymmetry, height, slope, skew, full width at half maximum, peak transmission, etc.).

FIG. **8** shows some absorption bands **71**, **88**, **90**, **92**, **94** for the same alkanes from FIG. **5** from 3000 nm to 3600 nm. In FIG. **8**, the pass band **80** for the optical bandpass filter **46** of a second embodiment is located between about 3300 nm and about 3400 nm with a full width at half maximum less than about 100 nm, for example. FIG. **9** shows some absorption bands **96**, **98** for the same alkenes from FIG. **6** from 3000 nm to 3600 nm. In FIG. **9**, the pass band **80** for the optical bandpass filter **46** of a third embodiment is located between about 3250 nm and about 3510 nm with a full width at half maximum less than about **250** nm, for example. FIG. **10** shows some absorption bands **100**, **102**, **104** for the same aromatics from FIG. **7** from 3000 nm to 3600 nm. In FIG. **10**, the pass band **80** for the optical bandpass filter **46** of a fourth embodiment is located between about 3200 nm and about 3580 nm with a full width at half maximum less than about 350 nm, for example.

FIG. **11** shows the first absorption band **71** for methane (see e.g., FIG. **3**A). In FIG. **11**, the pass band **80** for the optical bandpass filter **46** of a fifth embodiment is located between about 3200 nm and about 3350 nm with a full width at half maximum less than about 150 nm, for example. Hence, the fifth embodiment is adapted to visually detect methane leaks emanating from a component. FIG. **12** shows the second absorption band **72** for methane (see e.g., FIG. **3**A). In FIG. **12**, the pass band **80** for the optical bandpass filter **46** of a sixth embodiment is located between about 7600 nm and about 7800 nm with a full width at half maximum less than about 200 nm, for example. Thus, the sixth embodiment is also adapted to visually detect methane leaks emanating from a component.

FIG. **13** shows an absorption band **98** for ethylene located between about 3100 nm and about 3500 nm. In FIG. **13**, the pass band **80** for the optical bandpass filter **46** of a seventh embodiment is located between about 3200 nm and about 3500 nm with a full width at half maximum less than about 300 nm, for example. Hence, the seventh embodiment is adapted to visually detect ethylene leaks emanating from a component. FIG. **14** shows another absorption band **106** for ethylene, which is located between about 10000 nm and about 11500 nm. In FIG. **14**, the pass band **80** for the optical bandpass filter **46** of an eighth embodiment is located between about 10450 nm and about 10550 nm with a full width at half maximum less than about 100 nm, for example. Thus, the eighth embodiment is also adapted to visually detect ethylene leaks emanating from a component.

FIG. **15** shows an absorption band **96** for propylene located between about 3100 nm and about 3600 nm. In FIG. **15**, the pass band **80** for the optical bandpass filter **46** of a ninth embodiment is located between about 3200 nm and about 3600 nm with a full width at half maximum less than about 400 nm, for example. Hence, the ninth embodiment is adapted to visually detect propylene leaks emanating from a component. FIG. **16** shows another absorption band **108** for propylene, which is located between about 10000 nm and about 11500 nm. In FIG. **16**, the pass band **80** for the optical bandpass filter **46** of a tenth embodiment is located between about 10900 nm and about 11000 nm with a full width at half maximum less than about 100 nm, for example. Thus, the tenth embodiment is also adapted to visually detect propylene leaks emanating from a component.

FIG. **17** shows an absorption band **17** for 1,3 butadiene located between about 3100 nm and about 3500 nm. In FIG. **17**, the pass band **80** for the optical bandpass filter **46** of an eleventh embodiment is located between about 3150 nm and about 3300 nm with a full width at half maximum less than about 150 nm, for example. Hence, the eleventh embodiment is adapted to visually detect 1,3 butadiene leaks emanating from a component. Note that in another embodiment (not shown), the pass band of the eleventh embodiment may be located between about 3200 nm and about 3400 nm, for example, as another variation. If it is of particular interest to detect leaks of a certain chemical (or set of chemicals), it is preferred to have the pass band **80** overlaying the absorption band where the area under the absorption band is higher to provide better detection sensitivity. The width of the pass band **80** may or may not be critical for a given chemical, depending largely upon the characteristic shape of that chemical's absorption band (e.g., width along wavelength axis, height along absorption axis).

FIG. **18** shows another absorption band **112** for 1,3 butadiene, which is located between about 9000 nm and about 12000 nm. In FIG. **16**, the pass band **80** for the optical bandpass filter **46** of a twelfth embodiment is located between about 9000 nm and about 12000 nm with a full width at half maximum less than about 150 nm, for example. Thus, the twelfth embodiment is also adapted to visually detect 1,3 butadiene leaks emanating from a component. Note that the pass band **80** in FIG. **18** is not centered on the largest peak **114** of the absorption band **112**. In another embodiment (not shown), it may be preferred to have the pass band **80** centered at or closer to the largest peak **114** of the absorption band **112**.

FIG. **19** shows an absorption band **116** for sulfur hexafluorine (SF6) located between about 10000 nm and about 11500 nm. In FIG. **19**, the pass band **80** for the optical bandpass filter **46** of a thirteenth embodiment is located between about 10500 nm and about 10600 nm with a full width at half maximum less than about 100 nm, for example. Thus, the thirteenth embodiment is adapted to visually detect SF6 leaks emanating from a component. Sulfur hexafluorine is often used in switching gear for electrical equipment and its emissions are harmful to the environment. Hence, an embodiment of the present invention may be used to visually detect SF6 leaks emanating from electrical equipment, for example.

FIG. **20** shows a fourteenth embodiment of the present invention. In the fourteenth embodiment, the refrigeration system **60** of the infrared camera system **22** has a chamber **126** adapted to retain liquid nitrogen therein. The liquid nitrogen has thermal communication with the refrigerated portion **42** to cool the infrared sensor device **44** and optical bandpass filter **46** located therein. For the fourteenth embodiment, a currently preferred infrared camera system (**22**) is the InSb Laboratory Camera by Indigo System, Inc. of California, particularly when made portable (as shown in FIG. **20**). The frame **24**, battery **36**, and display screen **30** may be the same on the fourteenth embodiment (FIG. **20**) as that of the first embodiment (FIG. **1**). To provide for better viewing of the display screen **30** in a bright environment, a shroud, hood, or visor may be provided around the display screen **30**. For example, the fourteenth embodiment shown in FIG. **20** has a light shield **128** located proximate to the screen **30** for partially shielding the screen **30** from ambient light. During use, an inspector may place his face up to or against the edge of the shroud to shield the environmental light from the display screen **30** and allow the inspector to view the screen with the darkened enclosure formed.

An embodiment of the present invention may be used to inspect any of a wide variety of components having the chemical (or chemicals) of interest therein, including (but not limited to): a pipe, a compressor, an engine, a valve, a container, a tank, a switch, a reservoir, a fitting, a connector, a hose, a flare, an exhaust outlet, a machine, a vent for a blow-off valve, and combinations thereof, for example. Some example uses of embodiments of the present invention will be described next.

An embodiment of the present invention may be used to visually detect the evaporation (i.e., fumes) of petroleum products leaking from a component, such as a valve or pipe fitting. An advantage of an embodiment of the present invention over prior methods of detecting leaks (e.g., flame pack ionizer, sniffer device) is that the inspector can actually see the leak flowing by the visible image (representing the infrared image) provided by the infrared camera system **22**. Using a sniffer device, the sensor has to be within the flow stream to detect it, which requires close proximity and thorough scanning to cover an entire component or area. Using an embodiment of the present invention, an inspector can visually scan a large area in a much shorter period of time, and the inspector can do so from a distance. Thus, the inspector may not need to climb on and around equipment, which may be dangerous to the inspector. Also, pipes needing inspection are often located overhead along a roof, which is difficult to inspect with a sniffer device. But with an embodiment of the present invention, an inspector may stand below the pipes and perform the visual inspection using the infrared camera system **22** from the ground (from a distance).

Also, an inspector may combine the use of an embodiment of the present invention with other inspection methods. For example, after an inspector locates a leak visually with the infrared camera system **22** of an embodiment, the inspector could then do a further analysis of the leak using other measurement tools.

In a first method of using an embodiment of the present invention, an embodiment of the present invention (e.g., first embodiment) is used to visually inspect a natural gas (methane) regulator station **120**. Usually, such regulator stations are enclosed within the boundary of a fence **122**. As shown in FIG. **21**, an inspector **124** using an embodiment of the present invention may inspect the regulator station **120** from a location outside of the boundary defined by the fence **122**, even though the regulator station **120** is located within the boundary defined by the fence **122**. If the fence **122** cannot be seen through, as with a chain-link fence or a steel tubing fence, the inspector **124** may be able to visually inspect the regulator station **120** over the fence **122**. For example, the inspector **124** could stand on an object (e.g., truck bed). As another alternative, an inspector **124** could be lifted by a boom on a boom-truck, for example. Also, the inspector **124** may perform the inspection within the fence boundary **122**.

For most methods of using an embodiment of the present invention to visually detect a leak of a chemical (or chemicals) emanating from a component, the following steps will be performed. An inspector aims the infrared camera system **22** toward the component or components of interest. Infrared images of the component and background enter the camera system **22** via the lens assembly **40** (at least one lens **38**) (see e.g., camera system **22** in FIG. **2**). The infrared image passes through the optical bandpass filter **46** on its way to the infrared sensor device **44**. The infrared image is filtered by the optical bandpass filter **46** in accordance with the characteristics of the filter **46** (i.e., its pass band **80**). The filtered infrared image is then received by the infrared sensor device **44**, which converts the filtered infrared image to an electrical signal representing the filtered infrared image. This electrical signal is then electronically processed, within the camera system **22** (see e.g., FIG. **2**) and/or externally by another device outside of the camera system **22**, to provide a visible image representing the filtered infrared image. This visible image may be viewed in real time by the inspector, viewed by another person at another location (e.g., remotely located), recorded, transmitted to another device, transmitted to another location, or combinations thereof, for example.

In a method of the present invention, an inspector may obtain images and evaluate the images while performing the inspection. In another method, the inspector may do the same, and in addition, the images may be recorded and reviewed a second time. The second review may be performed by the same inspector, another person, or by a computer using image recognition software. The second review may find anything missed in the original survey. The ability to have a second review is not available with many conventional ways of doing leak surveys (e.g., using flame-packs) because a focused visual image of the inspection is not provided. Thus, a better leak survey requiring the same time and money (or less) may be performed using a method of the present invention, plus a visual record of the leak may be stored and may be viewed numerous times.

An advantage of an embodiment of the present invention is that it may allow the recording of the images obtained during the visual inspection. Such recordings may be useful in a number of ways. The recorded image obtained in the field may be transmitted (e.g., in real time or later) to a reviewer (person or computer system) at another location or a remote location. Sometimes in the field where bright conditions exist outside, for example, it may be difficult for the inspector to see small details on the video monitor or display screen. Also, the inspection conditions may not be conducive to a careful study of the image during the inspection. Thus, a reviewer located in a dark and stable environment may provide a better review of the images obtained by the system. The images may be recorded by a device attached to the infrared camera system, recorded at a remote location after being transmitted, or recorded by a separate device not attached to the infrared camera system **22**, for example. An image may be transmitted from the camera system **22** to another device (which may or may not be remotely located) by any of a wide variety of communication means, including (but not limited to): a cable, a wire, between wireless communication devices, via a network connection, via the Internet, or combinations thereof, for example. The images provided by the infrared camera system may be recorded continuously during an inspection and/or they may be recorded as desired over any period of time.

Referring to FIG. **21**, note that a video recording device is located in a carrying case separate from the infrared camera system. In other embodiments of the present invention, other components of the system may be separate from the infrared camera system (e.g., carried in a backpack). This may be preferred so that the camera system may be lighter and held easier. An embodiment is contemplated where most of the system components are located in a back pack or some other carrying case (e.g., case with wheels and handle) so that the camera portion having the lens, optical bandpass filter, and infrared sensors may be located in a smaller hand held unit. Such a hand held unit may include a small flat panel display screen, for example. It is also contemplated that the visible images from the camera may be displayed to an inspector using a system that projects the images directly into one or more of the inspector's eyes or onto an interior surface of a eyepiece or eyeglasses. One of ordinary skill in the art will realize many different types and sizes of display screens or projectors that may be incorporated into or used for an embodiment of the present invention.

It is also contemplated that an embodiment of the present invention may be made intrinsically safe to allow for greater flexibility and usages of the system for performing inspections. Also, providing an embodiment that incorporates an intrinsically safe infrared camera system may provide the advantage of entering plants for performing inspections without the need for a hot work permit to be issued and/or without the need for other safety precautions normally associated with the use of a non-intrinsically safe inspection system.

It is further contemplated that an embodiment of the present invention may incorporate a halogen light (e.g., attached to the camera system or separately provided) to provide a greater thermal contrast for the camera system using the heat radiated by the halogen light to change the temperature of the background slightly. It may be useful to use the halogen light on an as needed basis to get a more detailed image (higher sensitivity or better image resolution) of a leak after it is located (such as for making a recording of the leak).

The visual identification of a leak may be performed at another location remote from the infrared camera system and/or remote from the leak location, e.g., while viewing a recording of the images, while viewing an image transmitted to the remote location, or combinations thereof, for example. As an example, an inspection team flying over a transmission line in a helicopter (discussed further below) may be concentrating on obtaining a good image of the transmission line and precisely following GPS coordinates of the transmission line. While in a helicopter, it may be difficult for the inspection team to concentrate on reviewing the images obtained during the inspection process. The visual images obtained by the infrared camera system may be recorded for and/or transmitted to a reviewer. The reviewer may then carefully review the images to look for leaks. Such review may be performed in real-time, which would allow the reviewer to communicate with and instruct the inspectors to go back to a suspect location for a confirmation (i.e., hovering over a certain location and obtaining more images of a single location). Or if the visual inspections are recorded, a reviewer may study the inspection images at a later time. Hence, one of the members of the inspection team may later sit down in an environment more conducive to studying the images to provide the review of the images. Then, if needed or desired, a closer or more lengthy inspection of suspect locations may be performed later.

Government safety regulations and rules typically require that gas or petroleum product transmission lines and distribution lines be inspected at certain regular intervals. If a company does not comply with such rules and regulations, the company may be charged steep fines. Also, if there is some type of accident or incident where a leaking or ruptured line causes an explosion or fire, the company will want to provide evidence that they were diligent and not negligent in performing an inspection of that line. Hence, another benefit of being able to record a focused image of the visual inspection is the ability to have a record of the inspection. In an embodiment of the present invention, GPS coordinates, a date stamp, and/or a time stamp may be recorded onto or embedded within the recorded images of the visual inspection. This will provide evidence that an inspection was performed for a particular location at a particular date and time. Such records may be stored (in analog or digital format) on some type of storage medium (e.g., video tape, CD, DVD, database, hard drive, etc.) for future reference.

In a preferred embodiment and/or method of the present invention, inspection information may be displayed and/or recorded along with the recording/displaying of the visible image representing the filtered infrared image. The inspection information may include any relevant information desired, including (but not limited to): inspection location name, inspection location address, component name, component identification information, global positioning coordinates, a date, a time of day, an inspector's name, an inspection company's name, one or more camera system setting values, or combinations thereof, for example. Also, voice notes may be recorded onto or along with the images on a medium (e.g., voice notes recorded on a video of inspection). Such inspection information may be embedded within the visible image or may be recorded and tracked separately (e.g., in a separate file, as a header file, etc.).

In a second method of the present invention, an embodiment of the present invention may be used to inspect numerous fenced yards **130** from a single location, from outside the yards **130**, and/or from a single yard **130**. FIG. **22** shows a housing configuration found in many neighborhoods, where there is no alley behind the houses **132**. Instead, only a fence **134** may separate two or more adjacent backyards **130**. In FIG. **22**, an underground natural gas distribution line **136** is shown in dashed lines, which run across numerous backyards **130**. Using conventional leak survey techniques, an inspector would need to enter each backyard **130** to inspect the line in all six of the yards **130** shown in FIG. **22**. However, because a leak may be detected visually using an embodiment of the present invention, an inspector may enter only one backyard **130** and see into each of the adjacent yards **130** (as indicated by the arrows in FIG. **22**). Thus, only one customer needs to be disturbed for the inspection, rather than six. Also, an inspector may attach the infrared camera system **22** to a boom on a truck, or he may be standing in the boom holding the camera system **22**, located at an end of a street or in an alley to obtain visual access to numerous backyards **130**. Thus, using an embodiment of the present invention, multiple backyards may be surveyed for line leaks visually using an infrared camera system **22** from a single location (e.g., from a single backyard **130** looking over the fences **134**, or from a boom).

Many residential meters for natural gas are located next to a house (e.g., between houses), remote from where a vehicle may drive. Such distribution lines must be periodically tested for leaks. In such cases, using a conventional method of leak surveying, the inspector typically walks to each meter to perform the leak survey. In a third method of the present invention, such meters and distribution lines may be surveyed visually using an infrared camera system from a vehicle. For example, an inspector may aim an infrared camera system at the distribution lines while driving past each home without leaving the street or the vehicle. This can save a great deal of time and money for saved man hours. This same technique of using an embodiment of the present invention may be used for inspecting components located adjacent to or on any building, not just residential houses.

In a fourth method of performing an inspection with an embodiment of the present invention, the inspection may be performed in stages. A first stage may be that the inspector views the area of inspection using the infrared camera system from a distance to make sure there is not a huge leak that the inspector is about to walk or drive into. This would be mainly for the safety of the inspector. Many chemicals have little or no odor and are invisible to the human eye. Hence, an inspector could be driving or walking right into a very dangerous situation. Next, after the inspector confirms that there is not a huge leak (e.g., large flow of chemical emanating from the site), the inspector can perform a more detailed inspection looking for medium, small, and/or very small leaks.

Sometimes gas or chemical leaks or chemical spills in cities or near highways are reported to the police first, and the police send out officers to direct traffic away from the gas/chemical leak for the safety of the public. However, there have been instances where an officer drives right into the stream of the leak without knowing it and ignites an explosion, which may injure or kill the officer. The same dangers exist for repair persons entering such a location. Thus, it would be beneficial to incorporate a method of using an embodiment of the present invention into a first response system. For example, if a chemical leak/spill is suspected, a helicopter with an infrared camera system of an embodiment may be flown toward the suspected location to assess it visually from a safe distance using a method of the present invention. By doing so, the magnitude and direction of the fumes from a leak or spill may be determined and reported quickly and safely. It is often difficult to initially determine the magnitude of the leak or spill using conventional methods. As another example, an embodiment of the present invention could be used by firemen from their fire truck as they approach a scene of a reported leak or spill. Likewise, a maintenance or safety crew at a processing plant equipped with an embodiment of the present invention could assess a situation from a safe distance as they enter to investigate a suspected leak or spill.

The aiming of the infrared camera system of an embodiment towards a component being inspected may be performed from a vehicle. Part or all of the system may be attached to the vehicle or supported by the vehicle, and/or may be held be a person in the vehicle, for example. It may be any type or kind of vehicle suitable for the inspection, including (but not limited to): a truck, a car, a motorcycle, a bicycle, a boat, a ship, a personal watercraft, a fixed-wing airplane, a rotary wing vehicle (e.g., helicopter, gyro-plane), a powered paraglider, an ultralight aircraft, a powered glider, a glider, a balloon, a blimp, a remote controlled vehicle, an unmanned aerial vehicle, and combinations thereof. The vehicle may be moving or stopped during part or all of the inspection. If the infrared camera system is mounted on or attached to a vehicle, it may be desirable to have the camera system mounted on some type of stabilizing platform or stand, as is commonly used in the movie filming industry (e.g., gyro-stabilized apparatus). Such a stabilizing platform may provide the ability to obtain better images of a test site from a moving vehicle (e.g., truck, ATV, helicopter, blimp, airplane).

An embodiment may be attached to a satellite to provide inspections from space. One of the advantages of infrared is that it can see through most clouds. The range of inspection is limited only by a line of sight for a method of inspecting using an embodiment of the present invention. Hence, as long as the chemical leak or the trail of fumes emitted from the leak are within a line of sight (e.g., not blocked by trees, heavy rain, buildings, or structures), an infrared image may be obtained. The size/type/configuration of lens can thus be increased/decreased/varied as needed to provide focus for a given range.

The typical method of finding leaks on cross country transmission lines is to walk along the lines using a sniffer device (flame-pack detector), or in some cases where there are no fences one may drive a truck or ATV with mounted sniffers, up and down the lines. One of the disadvantages of this method is that if the wind is blowing away from the sniffer or if the vehicle or the walker is upwind from the leak, the sniffer probably will not detect a leak; thus missing the leak altogether. The next problem is that a lot of the gathering lines have now been overgrown with houses, buildings, and backyard fences. This makes it very impractical to check for leaks in and around residential back yards using conventional techniques. Companies often perform aerial surveys to look for encroachments or blocking of their easement. Such surveys may be performed simultaneous with a visual infrared inspection for leaks.

Also, truck mounted sniffers are actually built for leak detection in the cities not for cross country transmission lines. The difference being that the size of leak in cities versus transmission lines can be great. There is a danger of a pickup with a hot catalytic converter with grass stuck to it being driven onto a 200 mcf per day leak. Such a scenario can result in an explosion that can kill the driver and destroy the equipment. The conventional leak survey equipment requires the inspector to be in close proximity within the stream of gas flow to detect it. By the time the gas is detected for a large leak, it may be too late. Using an embodiment of the present invention, a large leak may be seen from more than ½ mile away, and other leaks may be seen from a distance.

An embodiment of the present invention may be attached to a helicopter or plane, for example, and flown over a transmission line at a relatively high rate of speed (e.g., 60-120 mph) while visual images are recorded using the infrared camera system. Even though the speed may be too great for an inspector to spot a leak on-the-fly, a computer image recognition system may be able to detect the leak at the higher speed, or a second review playing back the recording at a slower speed may be able to catch missed leaks.

Often the leaks in transmission lines are found by locating dead vegetation where the gas is leaking through the ground. However, during the winter when the grass is brown, this method may not work. Also in some areas, such as desert areas, there may be no vegetation where the leak exists. Thus, using a method of the present invention, leaks from a buried transmission line may be easily detected visually from a short or long distance away with an embodiment of the present invention.

Down in the swamp land of southern Louisiana, for example, it is almost impossible to walk the lines. Instead, the operators typically fly over their lines and look for discolored vegetation. However, a colony of ants can also leave an area of discolored vegetation that looks like a gas leak from the air. With an embodiment of the present invention mounted on a helicopter, for example, one may hover over an area suspected of having a leak, and record a short sequence of the specific area using the infrared camera system **22** to easily determine if there is a leak. In alternative, the entire line may be visually scanned using an infrared camera system **22** to look for leaks.

Most transmission lines have pressure gauges and automated valves at certain intervals (check points) along the line. Often an operator has the equipment to see a pressure drop across the line between points which may be 50-100 miles apart, for example. Along such a long distance between the two points, there may be several leaks. Typically, it is difficult to determine which of the leaks is larger. Thus, many smaller leaks may be fixed before finding the larger leak. Using an embodiment of the present invention, the larger leaks may be distinguished from the smaller leaks. Thus, the larger leaks may be located and repaired first, as they are usually the first priority.

Sometimes when one leak is being repaired, it can cause a new leak in the same pipe at another location due to movement of the pipe during the repair operation. In a method of the present invention, the nearby portions of the repaired line may be quickly and easily inspected visually using an embodiment of the present invention to determine whether another leak exists along that line.

When cast iron or old metal lines develop leaks, the pipe material often becomes saturated with the leaking gas. Also, the dirt around and above a gas leak (for any type of pipe) often becomes saturated with gas. Thus, after performing a repair and replacing the dirt, a sniffer detector may falsely indicate that the leak is still present because it may be detecting the remaining gas saturated in the dirt and/or pipe. Also, if the gas is odorized, the smell will often linger for several days as it slowly dissipates from the dirt, which can lead to follow-up complaints by persons still smelling the gas. However, performing a visual gas leak inspection with an embodiment of the present invention, may quickly determine whether the leak still exists after the repairs (before or after replacing the dirt). In most cases, the visual test will be able to distinguish remaining petroleum products saturated in the dirt and an actual leak (showing a stream of blowing gas, for example). This can save companies a lot of money on service calls and ensure that the leaks are actually fixed more accurately and more reliably.

Leak surveys in downtown business districts often have to be conducted at night due to traffic. With proper flight clearance, an infrared camera system **22** may be mounted on a helicopter, for example, to perform these leak surveys from a helicopter during the daytime and save overtime hours for crews. One of the advantages of performing a leak survey from above using an infrared camera system **22** to visually detect leaks is that the ground often retains heat to provide a good thermal contrast and thus a better background contrast for viewing the leak with infrared, as compared to the sky or a structure in many cases.

Another method of using an embodiment of the present invention is the detection of leaks in large tanker vessels transporting petroleum products by sea. Using an infrared camera system of an embodiment of the present invention, leaks to the environment may be detected visually from a safe distance (e.g., on land, on a dock) by the shipping company or by enforcement/regulatory agencies (e.g., EPA, DOT). Such ships carrying chemicals or petroleum products may be visually inspected as they pass by or as they approach, for example. Inspections may also be performed onboard the boat, ship, or vessel. Also, enclosed areas within a ship may be periodically or continuously monitored using a portable or permanently-installed/stationary infrared camera system of an embodiment, for example.

Another method of using an embodiment of the present invention is detecting gas leaks on petroleum production rigs. Often such rigs are approached via helicopter. An infrared camera system **22** adapted to visually image a petroleum product leak may be mounted on a crew helicopter. This would enable the crew on the helicopter to scan for gas leaks on gas platforms out in the ocean as they approach and before they land, for example. This would reduce or eliminate the risk of landing a helicopter with a hot engine into a gas leak. Furthermore, in another embodiment, a permanently-mounted/stationary infrared camera system **22** may be mounted at certain locations around the rig to provide a continuous or periodic visual leak survey.

In another method of using an embodiment of the present invention, detection of chemical leaks may be performed at factories, processing plants, manufacturing facilities, refineries, and/or petroleum separation plants. At some plants, they typically do monthly valve maintenance and inspections, for example. The problem with the way that they are currently done is that the flame-pack detector will often trigger on grease or WD-40 that is used on the valves for lubrication, for example. However, an infrared camera system **22** may be tuned (e.g., using an optical bandpass filter **46** having a certain pass band **80**) so that it does not have the ability to see or detect these greases and lubricants. Hence, such an embodiment may distinguish between the lubricants and gas leaks. If the fumes of the greases and/or lubricants are imaged by the camera system **22**, the visual observation of the fumes and the pattern of the fumes may allow the inspector to discern that it is not a leak and it is merely a lubricant evaporating. Often valves have been repacked due to a false leak detection triggered by lubricants on the valves, which is very costly and a waste of resources.

Another method of the present invention is the detection of leaks in the petrochemical industry or other chemical producing industries, using an embodiment of the present invention to visually detect leaks. Detection of such leaks may be performed at any stage from the exploration to the processing and production to the transporting of the chemicals produced to the containers storing the chemicals to the equipment using the chemicals, for example. A pipe or transportation line carrying the chemical may be visually inspected for leaks using an embodiment of the present invention. As another example, various pipes, connections, and equipment at a processing plant may be visually inspected or monitored for leaks using an embodiment of the present invention. Storage containers, cargo vessels, or truck trailers used for storing and/or transporting the chemicals may be visually inspected for leaks using an embodiment of the present invention, for example. Some example chemicals include (but are not limited to): ethylene, propylene, acetylene, propane, alcohol, ethanol, methanol, xylene, benzene, butadiene, acetone, compounds thereof, and combinations thereof.

An embodiment of the present invention may be used to perform a leak survey in and/or around a plant. An advantage of the present invention is that large leaks can be distinguished from small leaks, visually. Often the small leaks go unrepaired because they cannot be found easily using conventional methods. Even small leaks can be very dangerous in an enclosed area where flammable gases become trapped therein. Also, in many processing plants, the gases may have no odor added to them, which means a person would not smell the gases. Even where the gases are odorized, it is often difficult or impractical to detect all of the leaks. In most processing plants, the plant smells like chemicals everywhere because there are lots of small leaks. If the plant personnel could quickly and easily find the leaks, as they can using an embodiment of the present invention, it may become economical to fix even the smallest leaks. If that becomes the case, then processing plants may cease to smell like chemicals all the time. On one test of an embodiment of the present invention, 15 leaks were found in one region of a large plant in just 30 minutes, which is faster than most conventional methods of inspection. Another advantage of using an embodiment of the present invention is that the inspector often does not have to crawl on and around the equipment and pipes to find the leaks, as they may be seen with the infrared camera system when a line of sight is provided. Using a sniffer detector, however, an inspector would be required to get his detector within the flow of the gas leak to detect it.

Enclosed areas within a plant or any area at a plant may be periodically or continuously monitored using a portable or permanently-installed/stationary infrared camera system of an embodiment, for example. A permanently-mounted infrared camera of an embodiment may use a closed-cycle stirling cryocooler, for example, and may be similar to the first embodiment of FIG. **1** but adapted to be mounted in a building. An entire network of permanently mounted cameras may be strategically located throughout a plant to provide partial or complete coverage of the plant. In one embodiment, a person may monitor the images provided by the cameras continuously or periodically. In another embodiment, a computer system with image recognition software may be used to detect changes in the image or motion in an image indicating a stream of gas or liquid flow at a leak.

Also, many plants or factories have blow-off valves that vent out of the roof. A single plant may have numerous vents with vent exits being more than 30 feet high. However, using an infrared camera system in accordance with the present invention, gases exiting such vents may be quickly surveyed from a distance on the ground, for example. Also, flare emissions burning on the top of a tower structure may be visually inspected using an embodiment of the present invention from a distance (e.g., more than 10 feet away, from the ground, etc.).

Recorded inspection data from prior inspections may be useful for a plant manager. If an inspection is performed in a plant and the same leak is found again in a subsequent survey, as documented visually with video by inspectors, the plant manager can then know that either the leak was never repaired or it is a re-occurring leak.

In yet another method of using an embodiment of the present invention, government regulatory agencies (e.g., railroad commission, DOT, EPA) may themselves perform visual inspections easily and quickly using an infrared camera system to determine if a plant or factory is emitting petroleum products or other chemicals that should not be emitted into the environment (e.g., volatile organic compounds, volatile inorganic compounds, nitrous oxide, unburned chemicals, etc.). Such inspections by government regulatory agencies may be performed randomly as surprise inspections to enforce stricter compliance with environmental rules and regulations. Also, government regulatory agencies may require recordings of inspections to be retained so that they can review them. Furthermore, a government regulatory agency may then perform follow-up inspections visually at targeted areas where a leak was known from a prior inspection to ensure that the leaks were repaired in a timely manner. A government regulatory agency may also review a series of test videos to look for unrepaired leak scenarios. Thus, there are numerous methods of using an embodiment of the present invention that may be useful to a government regulatory agency.

In another method of the present invention, fuel leaks (or other chemical or fluid leaks) on a vehicle may be easily found using an embodiment of the present invention. For example, on a Lotus Esprit car, the gas tanks are notorious for rusting and developing small pinhole leaks which are difficult to locate and find. It is not cost efficient to remove the gas tanks for inspection, as the engine must be removed to get the gas tanks out of the vehicle. Also, such cars are notorious for having leaks at high pressure and/or low pressure fuel lines, which can cause engine fires. Furthermore, the toxic fumes from an engine bay where a fuel leak exists often make there way into the cabin, which is dangerous and obnoxious for the cabin occupants. An embodiment of the present invention may be used to accurately pinpoint and find such leaks. Also, such a method may be applied to locate fuel leaks in other vehicles, such as airplanes, boats, helicopter, and personal watercraft, for example. An infrared camera system **22** of the present invention may be used to locate refrigerant leaks quickly on a vehicle. Also, an embodiment of the present invention may be used to locate gas or refrigerant leaks in home or building HVAC equipment.

FIGS. **23**A-**31**B are some images generated by an embodiment of the present invention during experimental testing. Specifically, FIGS. **23**A-**31**B were generated using the fourteenth embodiment (see FIG. **20**) having an optical bandpass filter **46** with a pass band **80** about the same as that shown in FIG. **4**.

FIGS. **23**A-**23**D are visible images representing filtered infrared images of a gas **140** leaking from the ground (e.g., a buried line). The images of FIGS. **23**A-**23**D are from a sequence of images extracted from a video recording of this leak **140**. Although sometimes difficult to illustrate in still images, the movement of the leak stream **140** in a video (sequence of images) makes the leak **140** much more apparent. Very small leaks (low flowrate) that do not show up in one still image are often easily seen in a video because the movement of the leak stream or fumes can be seen in a video.

FIGS. **24**A-**24**D are images obtained by an embodiment of the present invention showing a gas **140** leaking from a compressor at a flange **142** on the discharge side. The sequence of images in FIGS. **24**A-**24**D were extracted from a video showing the gas **140** streaming from the flange **142**.

FIGS. **25**A-**25**D are images obtained by an embodiment of the present invention showing a natural gas (methane) leak **140** resulting from a crew cutting a 1 ½ inch gas line with approximately 12 psi pressure. It is an underground gas line (not shown). Although the large cloud of methane **140** exiting the hole in the ground is somewhat dispersed and difficult to see in the still images of FIGS. **25**A-**25**D, it is easily seen in the video due to the movement of the cloud **140**. Note also that the images of background objects are easy to discern and focused in the original video, which aids in providing a context of where the leak **140** is coming from.

FIG. **26** is an image obtained by an embodiment of the present invention and extracted from a recorded video sequence. FIG. **26** shows a large gas leak **140** emanating from a component **144** in a processing plant.

FIG. **27** is also an image obtained by an embodiment of the present invention and extracted from a recorded video sequence. FIG. **27** shows a gas **140** flowing from a vent tube **146** extending from a building roof **148** (about 30 feet high). This image was obtained by a person at ground level. The gas flowing out of the vent **146** may be from a blow-off valve that is exhausting to the environment, which may be indicative of a condition at that component causing the blow-valve to be opened.

FIGS. **28**A and **28**B are more images obtained by an embodiment of the present invention and extracted from a recorded video sequence. FIGS. **28**A and **28**B show a man pumping gasoline into his truck at a gas pump. Note in FIG. **28**B that as the gas is pumping into the gas tank, the gas fumes **140** can be seen just above the pump handle with the truck bed as the background.

FIG. **29** shows an image of propane **140** exiting a propane bottle in a test of the system for detecting propane. FIG. **30** shows an image of a small gas leak **140** emanating from a component at a processing plant. The leak appears as a faint black cloud **140** in the image. This is a relative small leak.

FIGS. **31**A and **31**B are images taken from a helicopter flying over a test site. In this test, a propane bottle was opened, as in FIG. **29**, in a field. In FIG. **31**A, the propane stream **140** can be seen with the infrared camera system at ½ mile away while the helicopter is moving toward the test site at about 60 knots. FIG. **31**B is a more focused image of the propane stream **140** at a closer distance than that of FIG. **31**A. Note that a person **150** can be seen standing next to the propane stream **140** and next to a bush **152** in FIG. **31**B. Also, note that two roads can be seen in FIGS. **31**A and **31**B, which provide reference points and context of the location of the propane stream **140**.

An advantage of an embodiment of the present invention, as illustrated in these images of FIGS. **23**A-**31**B, is that often the background and surrounding objects can be clearly seen in the image along with the leak or stream of gas **140**. This can be very useful in providing a reference or context of where the leak is located and aids in documenting the leak using video images.

In a recent test of an embodiment of the present invention before the US EPA, in comparison with other infrared camera systems, the embodiment of the present invention greatly outperformed the other systems. After this test before the US EPA, new US EPA regulations are expected to be released by the end of 2004, or shortly thereafter, allowing for the use of infrared camera systems to perform visual leak surveys. This demonstrates a long felt need in the industry that others have failed to meet, and that an embodiment of the present invention is now able to fulfill.

Also, after the US EPA test described above, there has been an explosive demand for embodiments of the present invention and for services using an embodiment of the present invention. This demonstrates the commercial success and great demand for embodiments of the present invention and for services using embodiments of the present invention.

FIG. **32** illustrates a schematic of a first dual camera embodiment of the present invention. This system includes a first video camera **22**, which is an infrared camera system with an optical bandpass filter **46** (preferably installed in a refrigerated portion **42** thereof, i.e., cold filter configuration); a second video camera **154** (e.g., another infrared camera system); an image splitter **156**; a lens assembly **158**; and an image processor/recorder **160**. The second video camera **154** may be any infrared camera system that can obtain an image from the same type of lens as the first video camera **22**. The second video camera **154** may be an infrared camera with filters so that it will not image the leaking chemical. The first video camera **22** is an infrared camera adapted to provide a focused visual image of a chemical leak by using an optical bandpass filter **46** for a specific pass band **80** (e.g., pass band **80** with a wavelength range centered at about 3.38 microns). For example, the first video camera **22** may be any of the embodiments discussed above (see e.g., FIGS. **1**-**20**). The first video camera **22** may receive the same image as the second video camera **154** from the same lens **158** via the image splitter **156**. The video signal from each camera may be output to the image processor/recorder **160**. The image processor/recorder **160** may simply record the two video feeds for later processing. In an alternative, the image processor/recorder **160** may be a system (e.g., a computer system running software for processing the video data) or specialized/dedicated hardware for processing the two video feeds.

Preferably, the images from the second video camera **154** are compared to the images from the first video camera **22** by a software program running on a computer system. Because a gas leak, for example, will not appear in the image from the second video camera **154**, the presence of the gas plume shown in the infrared image from the first camera **22** may be detected as a difference in the two video feeds.

In one embodiment, the software may automatically identify and map the pixel locations in the images for these differences corresponding to the gas plume in the infrared image. Then, the image of the gas plume (the differences shown in the infrared images from the first camera) is highlighted or colored to make it stand out in the image.

Optionally, the image processor/recorder **160** may be communicably coupled to a video monitor **162** (see FIG. **32**) and/or a database **164**, for example. The video monitor **162** may be used for an operator or inspector to view any one or more of the images or all of the images obtained while using the system **20**, for example. The database may be used as a repository or archive for the collected video images and test results. The first and second cameras **22**, **154** may be separate devices. In another embodiment, the image splitter **156**, lens **158**, first camera **22**, and second camera **154** may be integrally placed within a single portable unit. Likewise, the image processor/recorder **160** (or some portion thereof) may be placed within the same enclosure or on the same rack as the remainder of the system **20**.

FIG. **33** is a flowchart **168** showing an illustrative method that may be used for an embodiment (e.g., the embodiment shown in FIG. **32**) of the present invention. In this method of FIG. **33**, the images from both cameras may be recorded in the field and later processed in a vehicle or office. Also, using the method of FIG. **33**, the images of both cameras may be stored before being processed, even though the processing may be performed immediately thereafter (on-the-fly). The images from both cameras are compared to identify the differences (see block **170**), which may be indicative of chemical leak. Next, the differences are identified and mapped out. The mapped differences may then be added to the image from the second camera to provide a composite image. Also, when differences are identified (e.g., exceeding a predetermined number of pixels within the image, detecting movement), an alarm may be triggered to notify an operator or inspector of the suspected detection of a chemical leak.

In another method, illustrated in FIG. **34**, the infrared image from the first camera **22** and the composite image may be recorded. For example, the infrared image from the first camera may be needed for record keeping to maintain an unmodified image. However, the composite image may be preferred for reviewing by the inspections or for studying the inspections, as it may provide color coding or other visual or audio cues to help the reviewer to better identify potential leaks.

In still another method, illustrated in FIG. **35**, only the composite image may be recorded and the processing of the images may be performed as the images are collected. However, a temporary buffer memory (e.g., DRAM, MRAM) may be used during the processing.

FIG. **36** shows a simplified schematic for an alternative system **20** where the image splitter and mutual lens are not used. Thus, the first camera **22** receives its images separately from the second camera **154**. In this configuration, the second camera **154** may be a visible light camera, for example. FIG. **37** shows an illustrative flowchart **172** for a method where the system **20** of FIG. **36** may be used. The method of the FIG. **37** flowchart may be varied to provide a recording of the image (s) from the first and/or second cameras **22**, **154**. In other embodiments (not shown), additional camera(s) may be used as well (e.g., third camera). A video image from the second video camera **154** may be shown within a video image from the first camera **22** (picture-in-picture) to provide a reference view (e.g., full color visible light image) for the infrared image from the first camera **22**.

FIG. **38** shows an illustrative flowchart **174** for a method of an embodiment of the present invention. In this method, an alarm may be triggered if the comparison of images from the first and second cameras shows sufficient differences above a predetermined threshold (e.g., area of pixels, number of pixels, number of pixels per area, etc.) or movement in the image from the first camera that is not in the image from the second camera.

In another embodiment, one stationary-mounted camera (e.g., in an engine room) may be used. Often in certain areas of a plant there is rarely movement (e.g., no people moving about the room most times) in the room (other than unseen internal parts). In such embodiment, the image may be monitored by hardware or a computer system to detect movement in the image. Because the image is an infrared image taken with an infrared camera system of an embodiment, the movement may be caused by a chemical leak. Thus, the image may be continuously or periodically monitored for movement automatically. An alarm may be triggered when movement is detected to alert an operator to the suspected leak. Then, the operator may view the video image (past or present) to see if there is an actual leak.

In accordance with another aspect of the present invention, a passive infrared camera system adapted to provide a visual image of a chemical emanating from a component having the chemical therein, is provided. The passive infrared camera system includes a lens, a refrigerated portion, and a refrigeration system. The refrigerated portion includes therein an infrared sensor device adapted to capture an infrared image from the lens, and an optical bandpass filter located along an optical path between the lens and the infrared sensor device, wherein at least part of a pass band for the optical bandpass filter is within an absorption band for the chemical. The refrigeration system is adapted to cool the refrigerated portion of the infrared camera system.

The refrigeration system may include a chamber adapted to retain liquid nitrogen, for example. As another example, the refrigeration system may include a closed-cycle Stirling cryocooler. The refrigeration system may include a cryocooler system adapted to cool the infrared sensor device and the optical bandpass filter to a temperature below about 100 K. The passive infrared camera system is preferably portable and further includes a battery adapted to provide power for the infrared camera system during use of the infrared camera system. The passive infrared camera system may include a frame, a shoulder-rest portion extending from the frame, and a handle extending from the frame. The passive infrared camera system preferably includes a flat-panel screen adapted to display images obtained by the infrared camera system during use of the infrared camera system. The passive infrared camera system may further include a light shield located proximate to the screen and adapted to at least partially shield the screen from ambient light.

The optical bandpass filter may be adapted to allow a transmittance greater than about 45% of infrared light between about 3360 nm and about 3400 nm to pass therethrough, for example. As another example, the optical bandpass filter may be adapted to allow a transmittance greater than about 45% of infrared light between about 3350 nm and about 3390 nm to pass therethrough. The pass band of the optical bandpass filter may have a center wavelength located between about 3360 nm and about 3400 nm, for example. As another example, the pass band of the optical bandpass filter may have a center wavelength located between about 3375 nm and about 3385 nm, wherein the bandpass filter is adapted to allow a transmittance greater than about 80% of infrared light between about 3365 nm and about 3395 nm to pass therethrough, wherein the bandpass filter comprises a silicon dioxide substrate, and wherein the pass band has a full width at half maximum transmittance that is less than about 80 nm. As yet another example, the pass band of the optical bandpass filter may have a center wavelength located between about 3340 nm and about 3440 nm, wherein the bandpass filter is adapted to allow a transmittance greater than about 70% at the center wavelength, and wherein the pass band has a full width at half maximum transmittance that is less than about 100 nm. As still another example, the pass band of the optical bandpass filter may have a center wavelength between about 3360 nm and about 3380 nm, wherein the bandpass filter is adapted to allow a transmittance greater than about 70% at the center wavelength, and wherein the pass band has a full width at half maximum transmittance that is less than about 100 nm.

The infrared sensor device may include an Indium Antimonide focal plane array, wherein the focal plane array is enclosed in an evacuated dewar assembly. The pass band may have a full width at half maximum transmittance that is less than about 600 nm, for example. As another example, the pass band may have a full width at half maximum transmittance that is less than about 400 nm. As yet another example, the pass band may have a full width at half maximum transmittance that is less than about 200 nm. As still another example, the pass band may have a full width at half maximum transmittance that is less than about 100 nm. The pass band for the optical bandpass filter may be located between about 3100 nm and about 3600 nm, for example. As another example, the pass band for the optical bandpass filter may be located between about 3200 nm and about 3500 nm. As yet another example, the pass band for the optical bandpass filter may be located between about 3300 nm and about 3500 nm. The pass band for the optical bandpass filter may have a center wavelength located within the absorbance band for the chemical.

The component being inspected may be a pipe, a compressor, an engine, a valve, a container, a tank, a switch, a reservoir, a fitting, a connector, a hose, a flare, an exhaust outlet, a machine, a vent for a blow-off valve, or combinations thereof, for example. The refrigerated portion may be defined by an interior of a dewar container. The chemical may be methane, ethane, propane, butane, hexane, ethylene, propylene, acetylene, alcohol, ethanol, methanol, xylene, benzene, butadiene, formaldehyde, acetone, gasoline, diesel fuel, or combinations thereof, for example. The chemical may be petroleum, petroleum by-product, volatile organic compound, volatile inorganic compound, or combinations thereof, for example. The chemical may include a hydrocarbon, for example. As another example, the chemical may include methane, wherein the absorption band is at least partially located between about 3100 nm and about 3600 nm, wherein the pass band is located between about 3100 nm and about 3600 nm. The chemical may include methane, wherein the absorption band is at least partially located between about 7200 nm and about 8200 nm, wherein the pass band is located between about 7200 nm and about 8200 nm, for example. As yet another example, the chemical may include sulfur hexaflouride, wherein the absorption band is at least partially located between about 10400 nm and about 10700 nm, wherein the pass band is located between about 10400 nm and about 10700 nm. As still another example, the chemical may include ethylene, wherein the absorption band is at least partially located between about 3100 nm and about 3500 nm, wherein the pass band is located between about 3100 nm and about 3500 nm. The chemical may include ethylene, for example, wherein the absorption band is at least partially located between about 10400 nm and about 10700 nm, wherein the pass band is located between about 10400 nm and about 10700 nm. As another example, the chemical may include propylene, wherein the absorption band is at least partially located between about 3100 nm and about 3600 nm, wherein the pass band is located between about 3100 nm and about 3600 nm. As yet another example, the chemical may include propylene, wherein the absorption band is at least partially located between about 10000 nm and about 11500 nm, wherein the pass band is located between about 10000 nm and about 11500 nm. As still another example, the chemical may include 1,3 butadiene, wherein the absorption band is at least partially located between about 3100 nm and about 3200 nm, wherein the pass band is located between about 2900 nm and about 3200 nm. As a further example, the chemical may include 1,3 butadiene, wherein the absorption band is at least partially located between about 9000 nm and about 12000 nm, wherein the pass band is located between about 9000 nm and about 12000 nm.

The passive infrared camera system may include a video recording device adapted to record images obtained by the infrared camera system during use of the infrared camera system. The infrared camera system may be non-radiometric. The infrared camera system is preferably portable and non-radiometric.

In accordance with yet another aspect of the present invention, a passive infrared camera system adapted to provide a visual image of a chemical emanating from a component having the chemical therein, is provided. The passive infrared camera system includes a lens, a refrigerated portion, and a refrigeration system. In this case, the refrigerated portion includes therein an infrared sensor device adapted to capture an infrared image from the lens, and an optical bandpass filter located along an optical path between the lens and the infrared sensor device, the optical bandpass filter having a pass band with a full width at half maximum transmittance being less than about 600 nm, wherein at least part of the pass band for the optical bandpass filter is within an absorption band for the chemical. The refrigeration system is adapted to cool the refrigerated portion of the infrared camera system.

In accordance with still another aspect of the present invention, a passive infrared camera system adapted to provide a visual image of a chemical emanating from a component having the chemical therein, is provided. The passive infrared camera system includes a lens, a refrigerated portion, and a refrigeration system. In this case, the refrigerated portion includes therein an infrared sensor device adapted to capture an infrared image from the lens, and an optical bandpass filter located along an optical path between the lens and the infrared sensor device, wherein a pass band for the optical bandpass filter is located between about 3100 nm and about 3600 nm. The refrigeration system is adapted to cool the refrigerated portion of the infrared camera system.

In accordance with a further aspect of the present invention, a passive infrared camera system adapted to provide a visual image of a chemical emanating from a component having the chemical therein, is provided. The passive infrared camera system includes a lens, a refrigerated portion, a refrigeration system, and a battery. The refrigerated portion includes therein an infrared sensor device adapted to capture an infrared image from the lens, and an optical bandpass filter located along an optical path between the lens and the infrared sensor device, wherein at least part of a pass band for the optical bandpass filter is within an absorption band for the chemical. The refrigeration system is adapted to cool the refrigerated portion of the infrared camera system. The battery is electrically coupled to the infrared camera system, the infrared camera being adapted to be powered by the battery during use of the chemical leak inspection system.

In accordance with another aspect of the present invention, a portable chemical leak inspection system that includes a passive infrared camera system adapted to provide a focused visual image of a chemical emanating from a component having the chemical therein, is provided. The passive infrared camera system includes a lens, a refrigerated portion, and a refrigeration system. The refrigerated portion includes therein an infrared sensor device adapted to capture an infrared image from the lens, and an optical bandpass filter located along an optical path between the lens and the infrared sensor device, wherein at least part of a pass band for the optical bandpass filter is within an absorption band for the chemical. The refrigeration system is adapted to cool the refrigerated portion of the infrared camera system. The portable chemical leak inspection system also includes a battery, a frame, a shoulder-rest portion, and a handle. The battery is electrically coupled to the infrared camera system, the infrared camera being adapted to be powered by the battery during use of the chemical leak inspection system. The frame is attached to the infrared camera system. The shoulder-rest portion extends from the frame. And, the handle extends from the frame.

In accordance with yet another aspect of the present invention, a portable chemical leak inspection system that includes a passive infrared camera system adapted to provide a focused visual image of a chemical emanating from a component having the chemical therein, is provided. The passive infrared camera system includes a lens, a refrigerated portion, and a refrigeration system. In this case, the refrigerated portion includes therein an infrared sensor device adapted to capture an infrared image from the lens, and an optical bandpass filter located along an optical path between the lens and the infrared sensor device, wherein a pass band for the optical bandpass filter is located between about 3100 nm and about 3600 nm, and wherein the pass band has a full width at half maximum transmittance that is less than about 600 nm. The refrigeration system is adapted to cool the refrigerated portion of the infrared camera system. The portable chemical leak inspection system also includes a battery, a frame, a shoulder-rest portion, and a handle. The battery is electrically coupled to the infrared camera system, the infrared camera being adapted to be powered by the battery during use of the chemical leak inspection system. The frame is attached to the infrared camera system. The shoulder-rest portion extends from the frame. And, the handle extends from the frame.

In accordance with still another aspect of the present invention, a portable passive infrared camera system adapted to provide a focused visual image of a chemical emanating from a component having the chemical therein, is provided. The infrared camera system includes a lens, a dewar container, and a refrigeration system. The dewar container defines a refrigerated portion therein. The refrigerated portion includes therein an infrared sensor device having an array of sensors adapted to receive an infrared image from the lens and adapted to generate electrical signals corresponding to the infrared image, and an optical bandpass filter located along an optical path between the lens and the infrared sensor device, wherein a pass band for the optical bandpass filter is located between about 3100 nm and about 3600 nm, and wherein the pass band has a full width at half maximum transmittance that is less than about 600 nm. The refrigeration system is adapted to cool the refrigerated portion.

In accordance with a further aspect of the present invention, a portable passive infrared camera system adapted to provide a focused visual image of a chemical emanating from a component having the chemical therein, is provided. The infrared camera system includes a lens, a dewar container, and a refrigeration system. The dewar container defines a refrigerated portion therein. In this case, the refrigerated portion includes therein an infrared sensor device having an array of sensors adapted to receive an infrared image from the lens and adapted to generate electrical signals corresponding to the infrared image, and an optical bandpass filter located along an optical path between the lens and the infrared sensor device, wherein a pass band for the optical bandpass filter is located between about 3200 nm and about 3500 nm, wherein the pass band has a full width at half maximum transmittance that is less than about 80 nm, and wherein the pass band has a center wavelength located between about 3320 nm and about 3440 nm. The refrigeration system is adapted to cool the refrigerated portion.

Although embodiments of the present invention and at least some of its advantages have been described in detail, it should be understood that various changes, substitutions, and alterations can be made herein without departing from the spirit and scope of the invention as defined by the appended claims. Moreover, the scope of the present application is not intended to be limited to the particular embodiments of the process, machine, manufacture, composition of matter, means, methods, and steps described in the specification. As one of ordinary skill in the art will readily appreciate from the disclosure of the present invention, processes, machines, manufacture, compositions of matter, means, methods, or steps, presently existing or later to be developed, that perform substantially the same function or achieve substantially the same result as the corresponding embodiments described herein may be utilized according to the present invention. Accordingly, the appended claims are intended to include within their scope such processes, machines, manufacture, compositions of matter, means, methods, or steps.

What is claimed is:

1. A method of visually detecting a gas leak of any one or more chemicals of a group of predetermined chemicals, the gas leak emanating from a component of a group of components in different locations, the method comprising:

aiming a passive infrared camera system towards the component, wherein the passive infrared camera system comprises:
  a lens,
  a refrigerated portion defined by the interior of a Dewar flask, the refrigerated portion comprising therein:
    an infrared sensor device; and
    a single filter configuration comprising at least one fixed optical bandpass filter, each filter fixed along an optical path between the lens and the infrared sensor device, wherein at least part of the aggregate pass band for the single filter configuration is within an absorption band for each of the predetermined chemicals and wherein the aggregate pass band for the single filter configuration is at least about 200 nm; and
  a refrigeration system adapted to cool the refrigerated portion, the refrigeration system comprising a closed-cycle Stirling cryocooler;
filtering an infrared image associated with the area of the gas leak under normal operating and ambient conditions for the component with the at least one optical bandpass filter;

receiving the filtered infrared image of the gas leak with the infrared sensor device;

electronically processing the filtered infrared image received by the infrared sensor device to provide a visible image of the gas leak under variable ambient conditions of the area around the leak; and

visually detecting the leak based on the visible image under the variable ambient conditions.

2. The method of claim **1**, further comprising recording the visible image representing the filtered infrared image provided by the infrared camera system, wherein the visual identification of the leak is performed at another location remote from the component while viewing the recorded visual image.

3. The method of claim **1**, further comprising:

transmitting the visible image representing the filtered infrared image provided by the infrared camera system to another location remote from the component, wherein the visual identification of the leak is performed at the remote location; and

recording the visible image representing the filtered infrared image provided by the infrared camera system at the remote location.

4. The method of claim **1**, further comprising recording the visible image representing the filtered infrared image along with inspection information, wherein the inspection information is selected from a group consisting of inspection location name, inspection location address, component name, component identification information, global positioning coordinates, a date, a time of day, an inspector's name, an inspection company's name, one or more camera system setting values, and combinations thereof.

5. The method of claim **1**, wherein the aiming of the infrared camera system towards the component is performed from a moving vehicle selected from a group consisting of a truck, a car, a motorcycle, a bicycle, a boat, a ship, a personal watercraft, a fixed-wing airplane, a rotary wing vehicle, a powered paraglider, an ultralight aircraft, a powered glider, a glider, a balloon, a blimp, a remotely controlled vehicle, an unmanned aerial vehicle, and combinations thereof.

6. The method of claim **5**, wherein the vehicle is a helicopter and the component is a pipeline, wherein the pipeline is at least partially buried in the ground.

7. The method of claim **1**, wherein the infrared camera system is portable, wherein the infrared camera system further comprises a frame, a shoulder-rest portion extending from the frame, and a handle extending from the frame, and wherein the aiming of the infrared camera system towards the component is performed by a person holding the infrared camera system.

8. The method of claim **1**, wherein the aiming of the infrared camera system towards the component is performed from a satellite, and wherein the component is located on Earth.

9. The method of claim **1**, wherein the aiming of the infrared camera system towards the component is performed from outside of a boundary defined by a fence, and wherein the component is located within the boundary.

10. The method of claim **1**, wherein the component is located on a ship, wherein the aiming of the infrared camera system towards the component is performed from a location not on the ship.

11. The method of claim **1**, wherein the component is selected from the group consisting of a component within a building, a component located at a processing plant, a component located on a ship, a component located on an offshore rig, a component located at least 10 feet from the infrared camera system, a component located above a majority of a structure, a component located on a vehicle, a pipe, a compressor, an engine, a valve, a container, a tank, a switch, a reservoir, a fitting, a connector, a hose, a flare, an exhaust outlet, a machine, a vent for a blow-off valve, and combinations thereof.

12. The method of claim **1**, wherein the refrigeration system is adapted to cool the infrared sensor device and the optical bandpass filter to a temperature below about 100 K.

13. The method of claim **1**, wherein the infrared camera system is non-radiometric.

14. The method of claim **1**, wherein the infrared sensor device comprises an Indium Antimonide focal plane array of at least 81,920 sensor elements.

15. The method of claim **1**, wherein the aggregate pass band for the single filter configuration has a center wavelength located within the absorbance band for the chemical emanating from the component.

16. The method of claim **1**, wherein the any one or more chemicals comprises any one or more substance selected from the group consisting of refrigerant, fuel, water vapor, methane, ethane, propane, butane, hexane, ethylene, propylene, acetylene, alcohol, ethanol, methanol, xylene, benzene, butadiene, acetone, gasoline, diesel fuel, petroleum, petroleum by-product, volatile organic compound, volatile inorganic compound, a hydrocarbon, and combinations thereof.

17. The method of claim **1**, wherein the infrared sensor device includes an Indium Antimonide focal plane array, wherein the aggregate pass band for the single filter configuration is between 3250 nm and 3510 nm, and further including cooling the infrared sensor device and the optical bandpass filter to a temperature below about 100° K with the refrigeration system.

18. A method of visually detecting a gas leak of any one or more chemicals of a group of predetermined chemicals, the gas leak emanating from a component of a group of components in different locations, the method comprising:

aiming a passive infrared camera system towards the component, wherein the passive infrared camera system comprises:
  a lens,
  a refrigerated portion defined by the interior of a Dewar flask, the refrigerated portion comprising therein:
    an infrared sensor device; and
    a single filter configuration comprising at least one fixed optical bandpass filter, each filter fixed along an optical path between the lens and the infrared sensor device, the single filter configuration comprising an aggregate pass band with a full width at half maximum transmittance being less than about 600 mn, wherein at least part of the aggregate pass band for the single filter configuration is within an absorption band for each of the predetermined chemicals and wherein the aggregate pass band for the at least one optical bandpass filter is at least about 200 mn; and
  a refrigeration system adapted to cool the refrigerated portion, the refrigeration system comprising a closed-cycle Stirling cryocooler;

receiving an infrared image with the infrared sensor device of the gas leak under normal operating and ambient conditions for the component, after the infrared image passes through the lens and the at least one optical bandpass filter, and after the infrared image is filtered by the at least one optical bandpass filter;

electronically processing the filtered infrared image received by the infrared sensor device to provide a visible image of the gas leak under variable ambient conditions of the area around the leak; and

visually detecting the leak based on the visible image under the variable ambient conditions.

19. A method of visually detecting a gas leak of any one or more chemicals of a group of predetermined chemicals, the gas leak emanating from a component of a group of components in different locations, the method comprising:

aiming a passive infrared camera system towards the component, wherein the passive infrared camera system comprises:

a lens,

a refrigerated portion defined by the interior of a Dewar flask, the refrigerated portion comprising therein:

an infrared sensor device; and

a single filter configuration comprising at least one fixed optical bandpass filter, each filter fixed along an optical path between the lens and the infrared sensor device, wherein the aggregate pass band for the single filter configuration is at least from about 3100 nm to about 3600 nm and at least about 200 nn and wherein at least part of the aggregate pass band for single filter configuration is within the absorption band for each of the predetermined chemicals; and

a refrigeration system adapted to cool the refrigerated portion, the refrigeration system comprising a closed-cycle Stirling ciyocooler;

receiving an infrared image with the infrared sensor device of the gas leak under normal operating and ambient conditions for the component, after the infrared image passes through the lens and the at least one optical bandpass filter, and after the infrared image is filtered by the at least one optical bandpass filter;

electronically processing the filtered infrared image received by the infrared sensor device to provide a visible image of the gas leak under variable ambient conditions of the area around the leak; and

visually detecting the leak based on the visible image under the variable ambient conditions.

20. A method of visually detecting a gas leak of any one or more chemicals of a group of predetermined chemicals, the gas leak emanating from a component of a group of components in different locations, the method comprising:

aiming a passive infrared camera system towards the component, wherein the passive infrared camera system comprises:

a lens,

a refrigerated portion defined by the interior of a Dewar flask, the refrigerated portion comprising therein:

an infrared sensor device; and

a single filter configuration comprising at least one fixed optical bandpass filter, each filter fixed along an optical path between the lens and the infrared sensor device, wherein the aggregate pass band for the single filter configuration is at least from about 3200 nm to about 3500 nm, is at least 200 nm, and has a center wavelength located between about 3320 nm and about 3440 nm, and wherein at least part of the aggregate pass band for the single filter configuration is within the absorption band for each of the predetermined chemicals; and

a refrigeration system adapted to cool the refrigerated portion, the refrigeration system comprising a closed-cycle Stirling cryocooler;

receiving an infrared image with the infrared sensor device of the gas leak under normal operating and ambient conditions for the component, after the infrared image passes through the lens and is filtered by the single filter configuration;

electronically processing the filtered infrared image received by the infrared sensor device to provide a visible image of the gas leak under variable ambient conditions of the area around the leak; and

visually detecting the leak based on the visible image under the variable ambient conditions.

* * * * *

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(12) **United States Patent**
Furry

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(54) **CHEMICAL LEAK INSPECTION SYSTEM**

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This patent is subject to a terminal disclaimer.

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(60) Provisional application No. 60/477,994, filed on Jun. 11, 2003, provisional application No. 60/482,070, filed on Jun. 23, 2003, provisional application No. 60/540,679, filed on Jan. 30, 2004.

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G01J 5/02 (2006.01)

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USPC **250/330**; 250/339.03

(58) **Field of Classification Search** 250/330, 250/339.03
See application file for complete search history.

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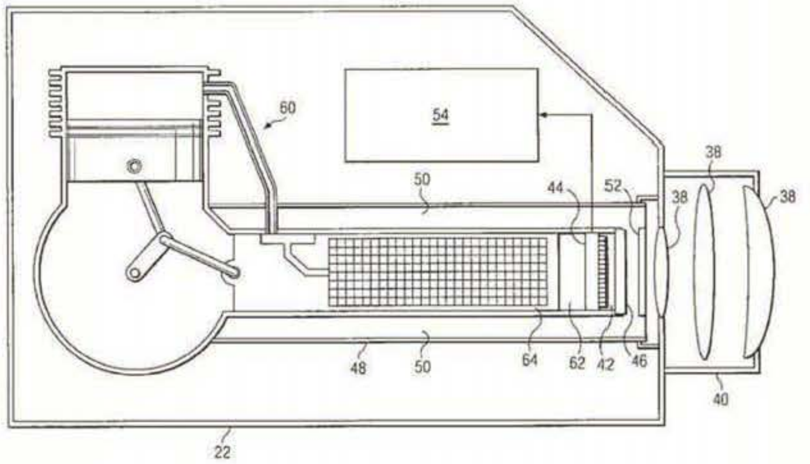
(57) **ABSTRACT**

A method of visually detecting a leak of a chemical emanating from a component includes aiming a passive infrared camera system towards the component; filtering an infrared image with an optical bandpass filter, the infrared image being that of the leak; after the infrared image passes through the lens and optical bandpass filter, receiving the filtered infrared image with an infrared sensor device; electronically processing the filtered infrared image received by the infrared sensor device to provide a visible image representing the filtered infrared image; and visually identifying the leak based on the visible image. The passive infrared camera system includes: a lens; a refrigerated portion including the infrared sensor device and the optical bandpass filter (located along an optical path between the lens and the infrared sensor device). At least part of a pass band for the optical bandpass filter is within an absorption band for the chemical.

58 Claims, 31 Drawing Sheets



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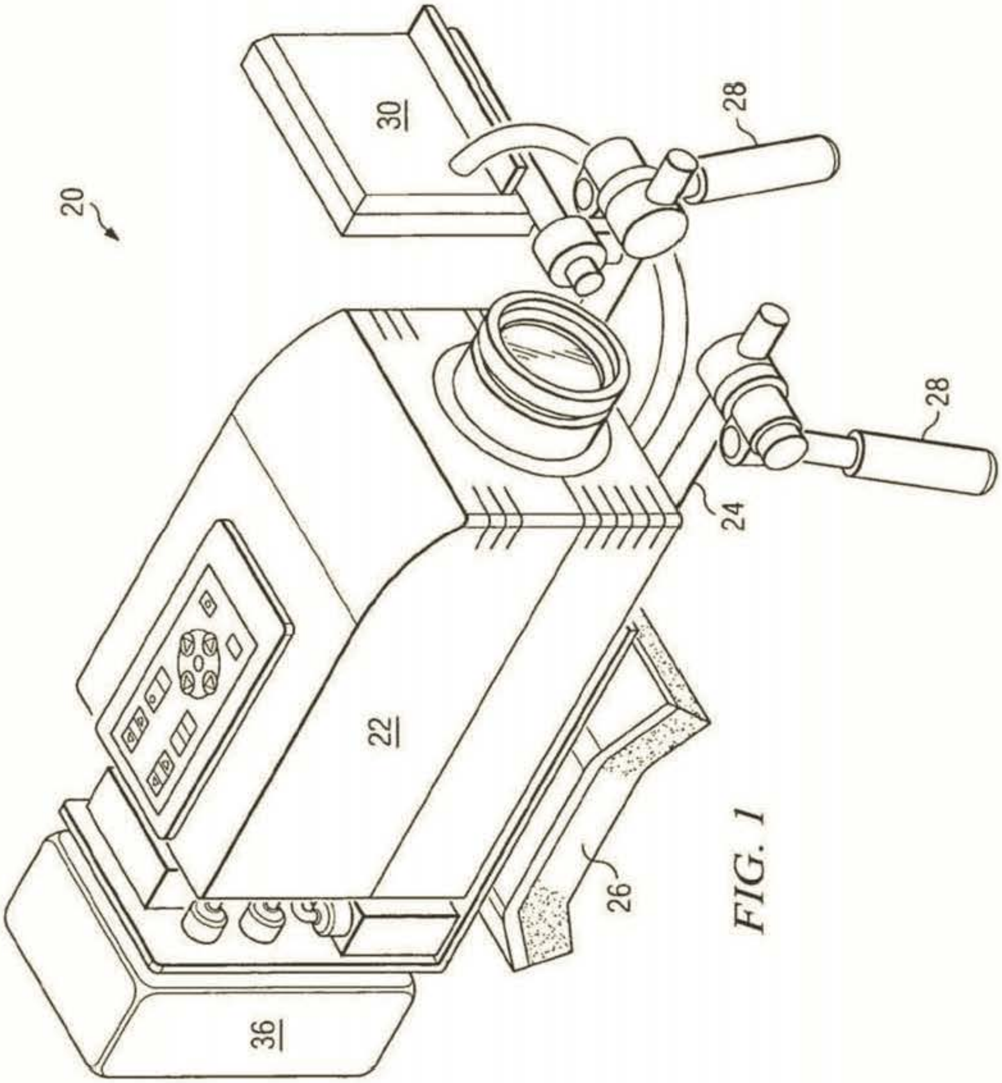

FIG. 1

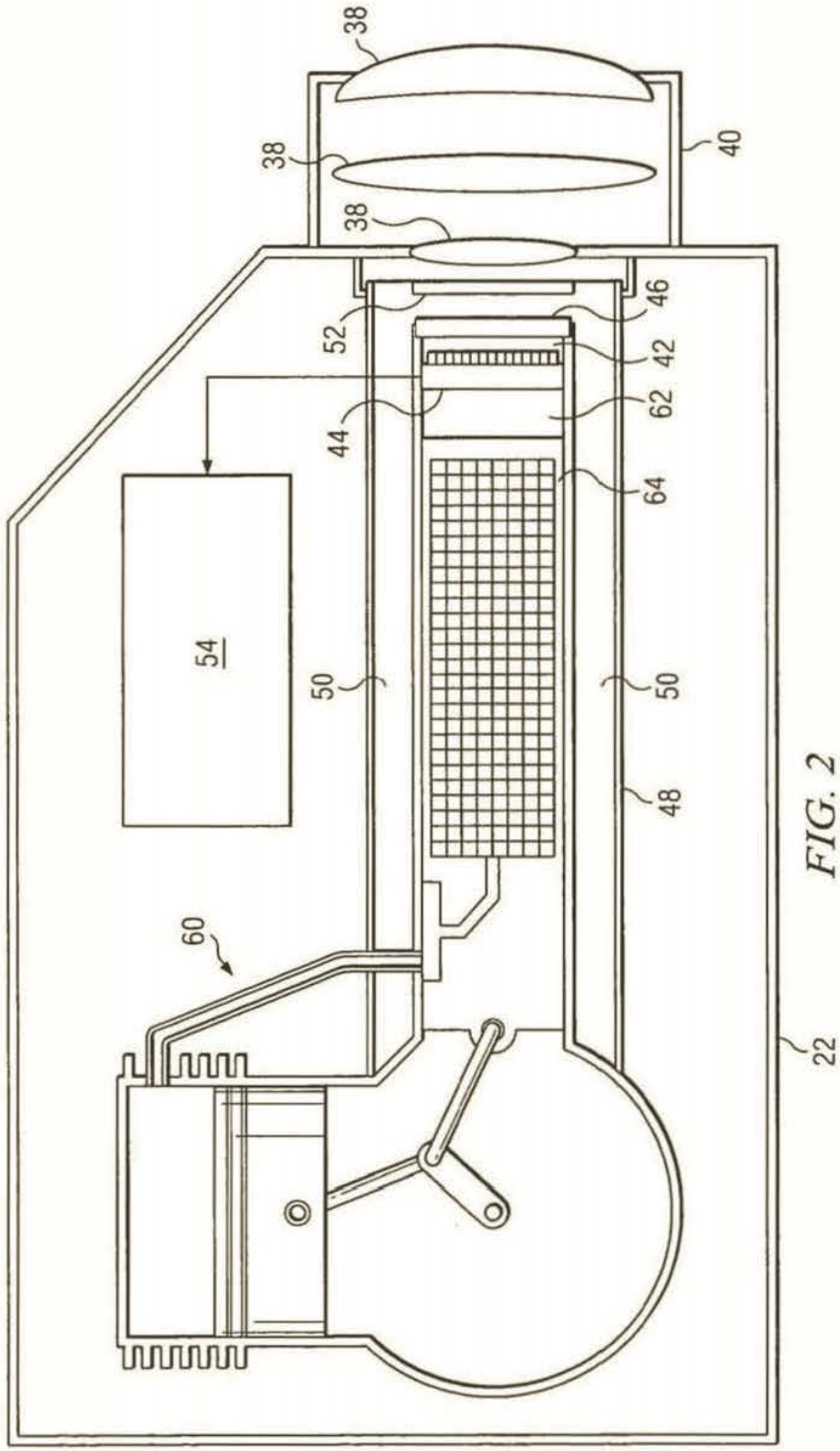

FIG. 2

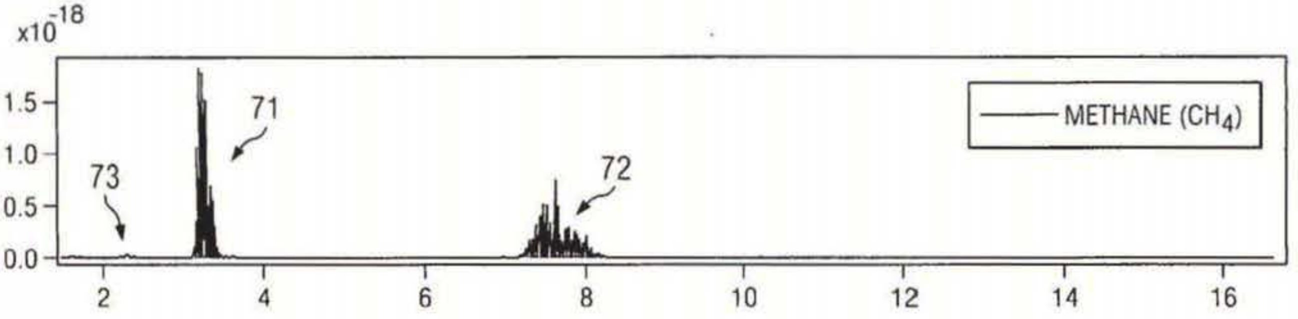
x10-18
1.5
1.0
0.5
0.0
73
71
72
METHANE (CH4)
2
4
6
8
10
12
14
16

FIG. 3A

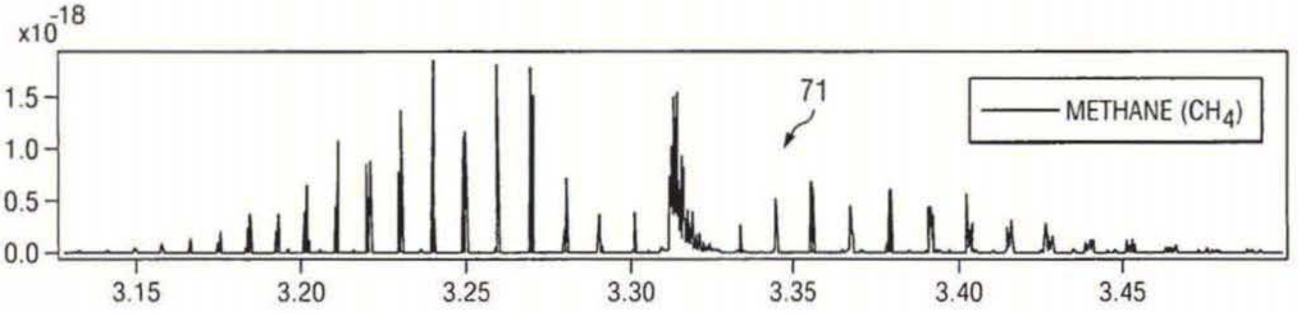
x10-18
1.5
1.0
0.5
0.0
71
METHANE (CH4)
3.15
3.20
3.25
3.30
3.35
3.40
3.45

FIG. 3B

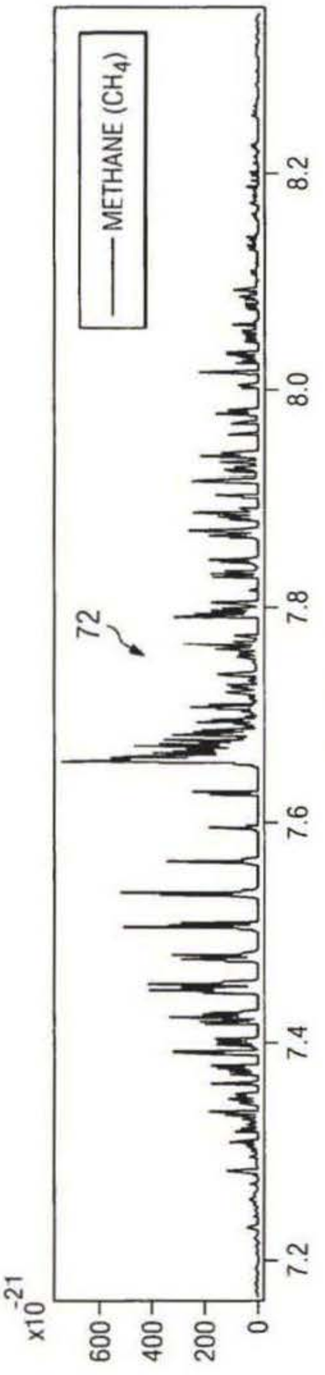
x10^{-21}
600
400
200
0
7.2
7.4
7.6
7.8
8.0
8.2
METHANE (CH_4)
72

FIG. 3C

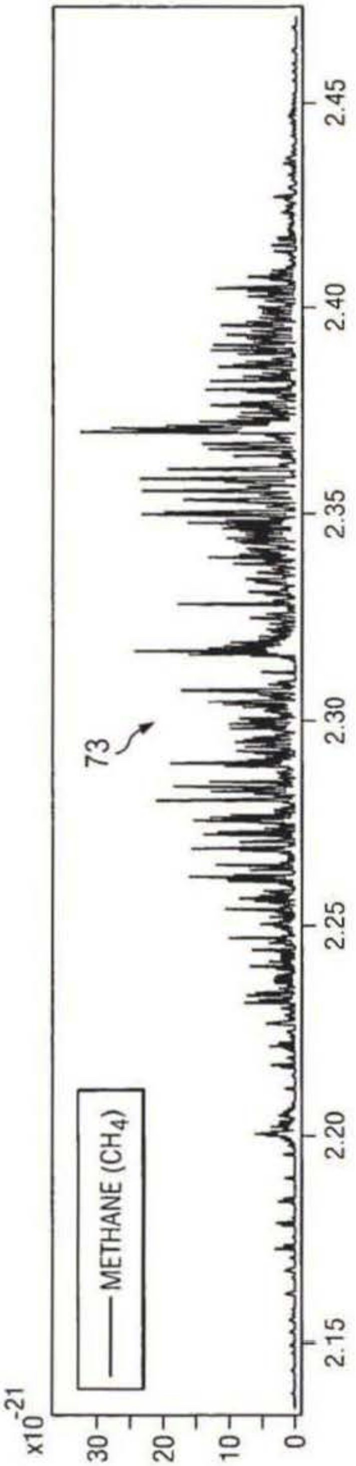
x10^{-21}
30
20
10
0
2.15
2.20
2.25
2.30
2.35
2.40
2.45
METHANE (CH_4)
73

FIG. 3D

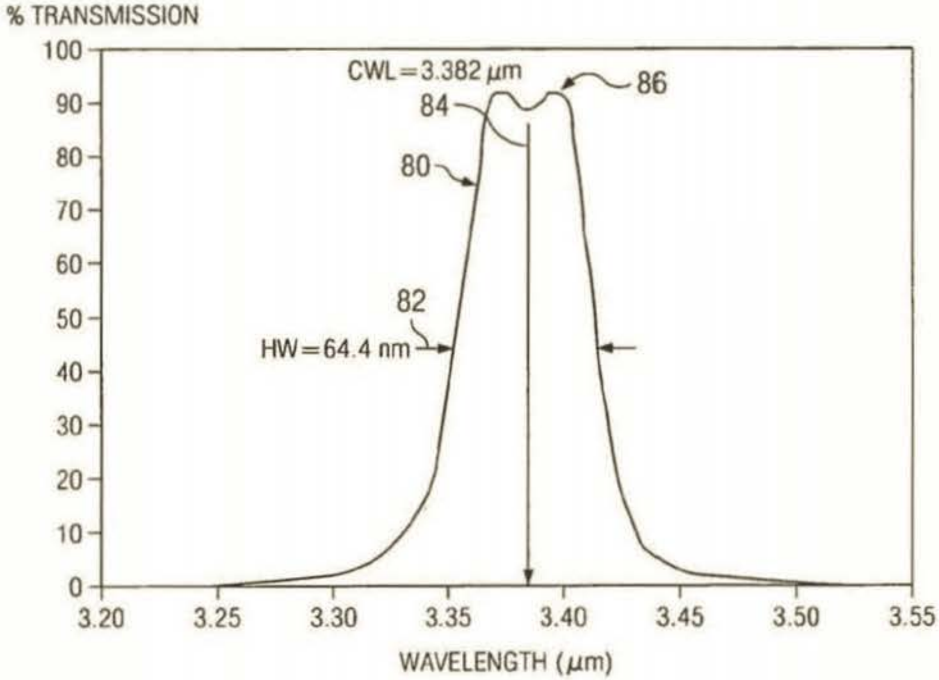
% TRANSMISSION
100
90
80
70
60
50
40
30
20
10
0
CWL=3.382 µm
84
86
80
82
HW=64.4 nm
3.20
3.25
3.30
3.35
3.40
3.45
3.50
3.55
WAVELENGTH (µm)

FIG. 4

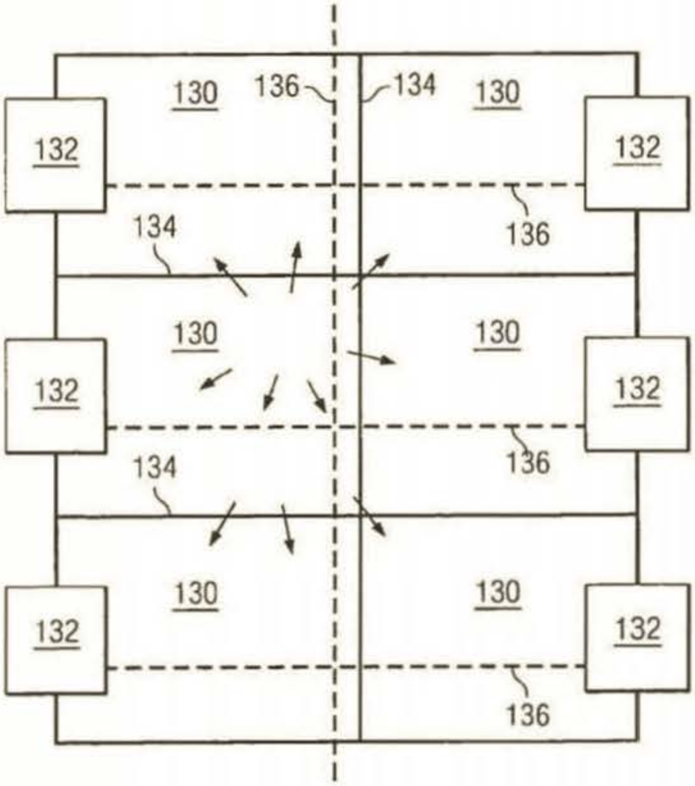
130
136
134
130
132
132
134
136
130
130
132
132
134
136
130
130
132
132
136

FIG. 22

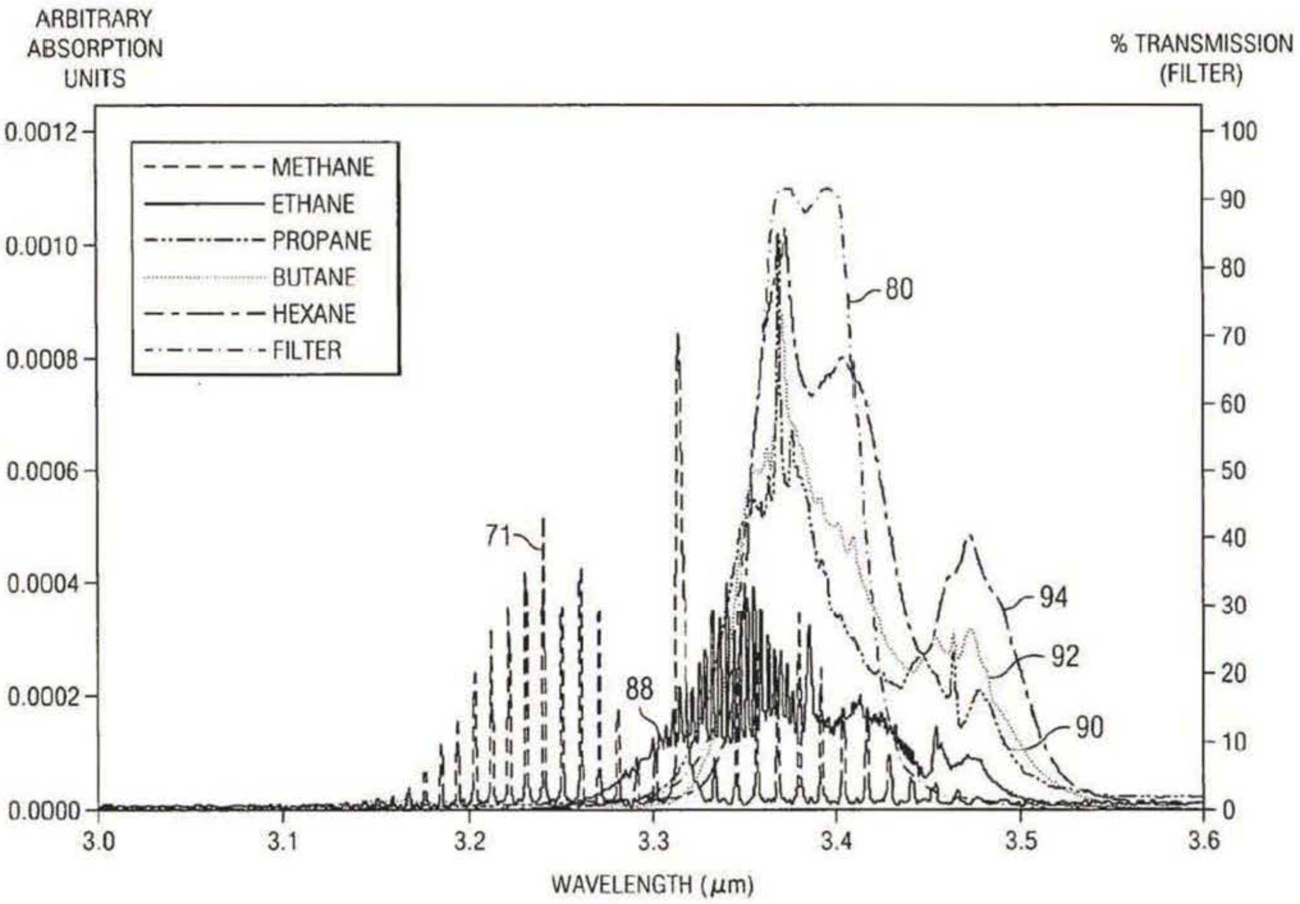
ARBITRARY ABSORPTION UNITS
% TRANSMISSION (FILTER)
METHANE
ETHANE
PROPANE
BUTANE
HEXANE
FILTER
0.0012
0.0010
0.0008
0.0006
0.0004
0.0002
0.0000
100
90
80
70
60
50
40
30
20
10
0
3.0
3.1
3.2
3.3
3.4
3.5
3.6
WAVELENGTH (μm)
71
80
88
94
92
90

FIG. 5

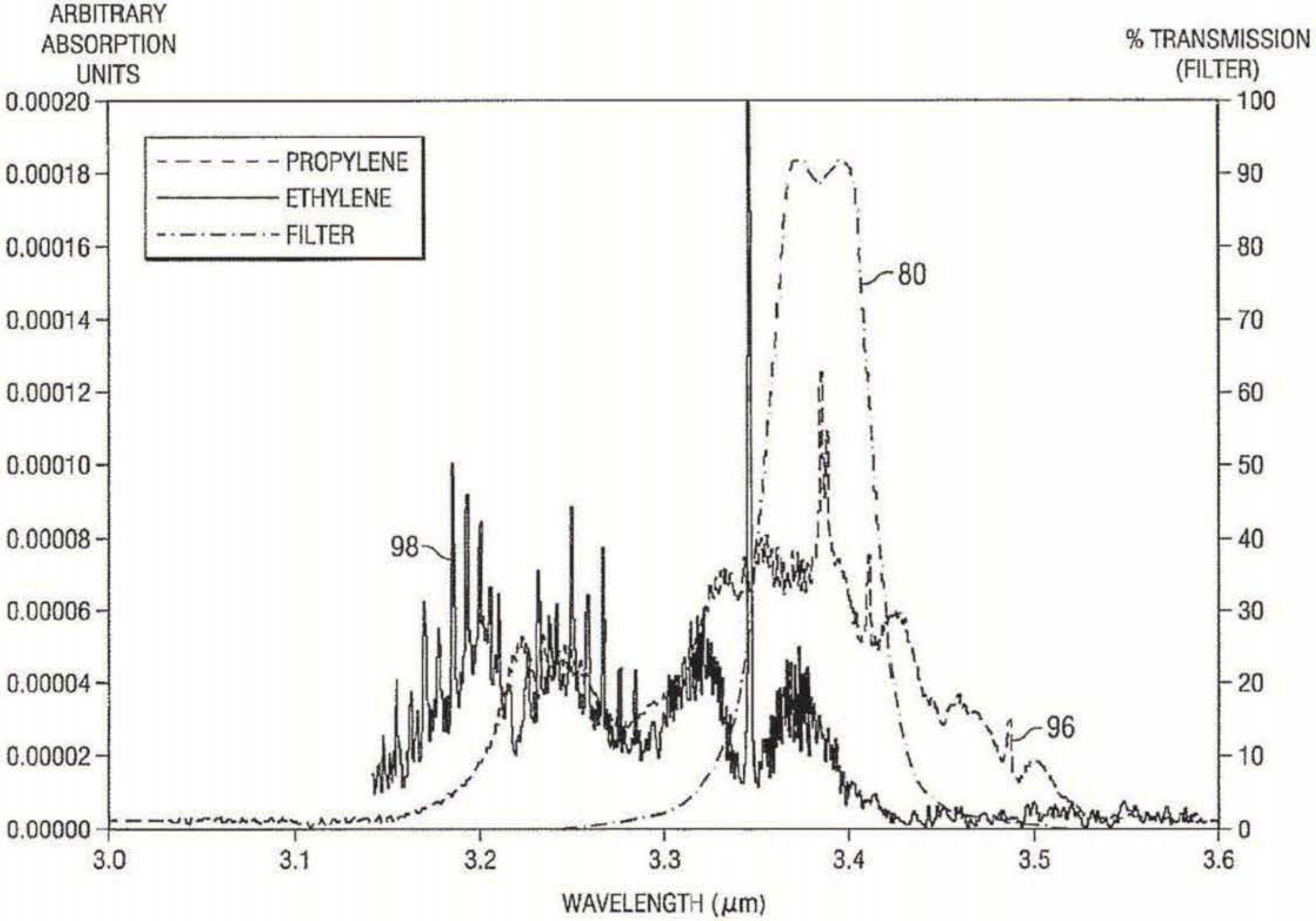
ARBITRARY ABSORPTION UNITS
% TRANSMISSION (FILTER)
PROPYLENE
ETHYLENE
FILTER
0.00020
0.00018
0.00016
0.00014
0.00012
0.00010
0.00008
0.00006
0.00004
0.00002
0.00000
100
90
80
70
60
50
40
30
20
10
0
3.0
3.1
3.2
3.3
3.4
3.5
3.6
WAVELENGTH (μm)
80
98
96

FIG. 6

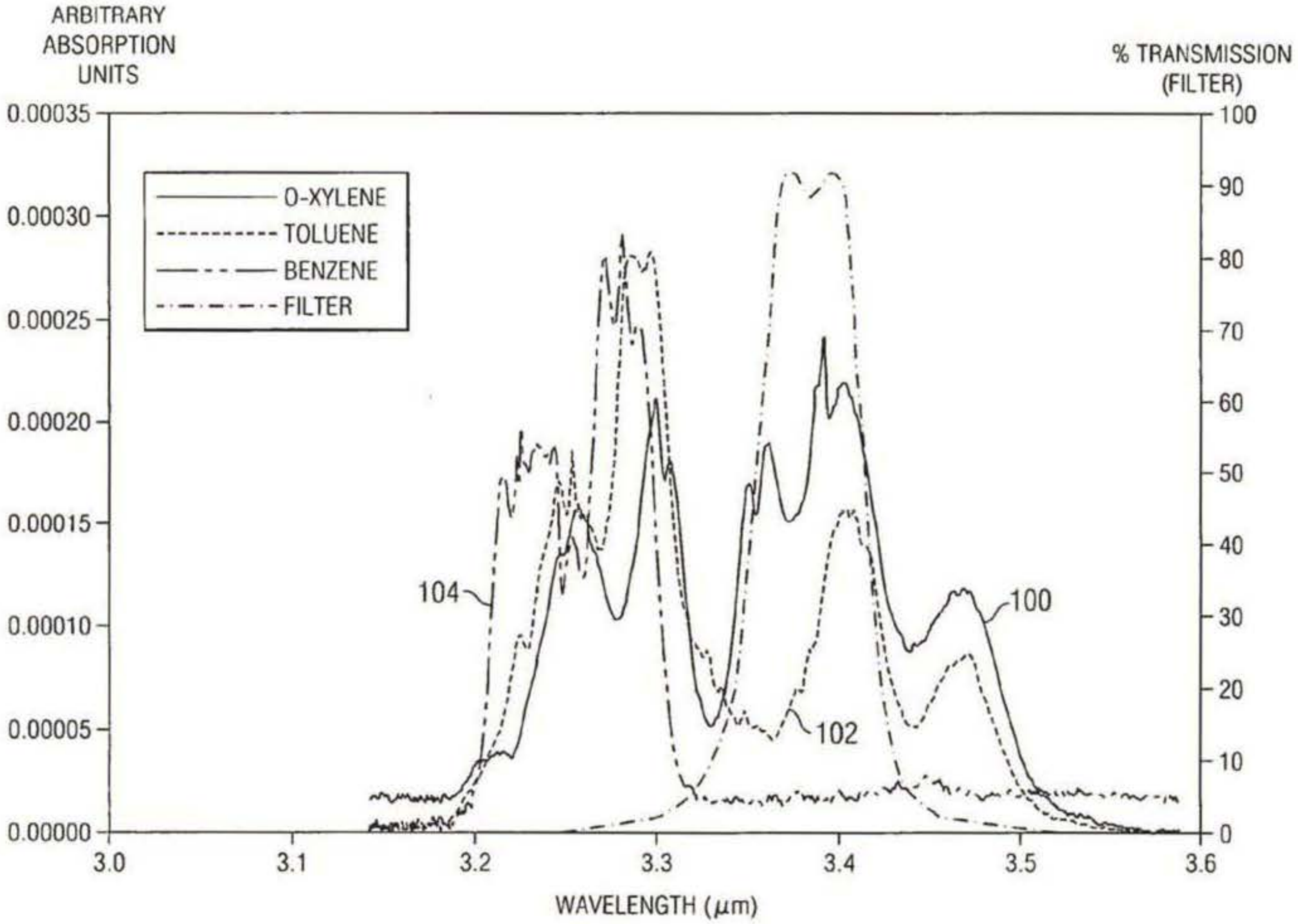
ARBITRARY ABSORPTION UNITS
% TRANSMISSION (FILTER)
0.00035
0.00030
0.00025
0.00020
0.00015
0.00010
0.00005
0.00000
100
90
80
70
60
50
40
30
20
10
0
O-XYLENE
TOLUENE
BENZENE
FILTER
104
102
100
3.0
3.1
3.2
3.3
3.4
3.5
3.6
WAVELENGTH (μm)

FIG. 7

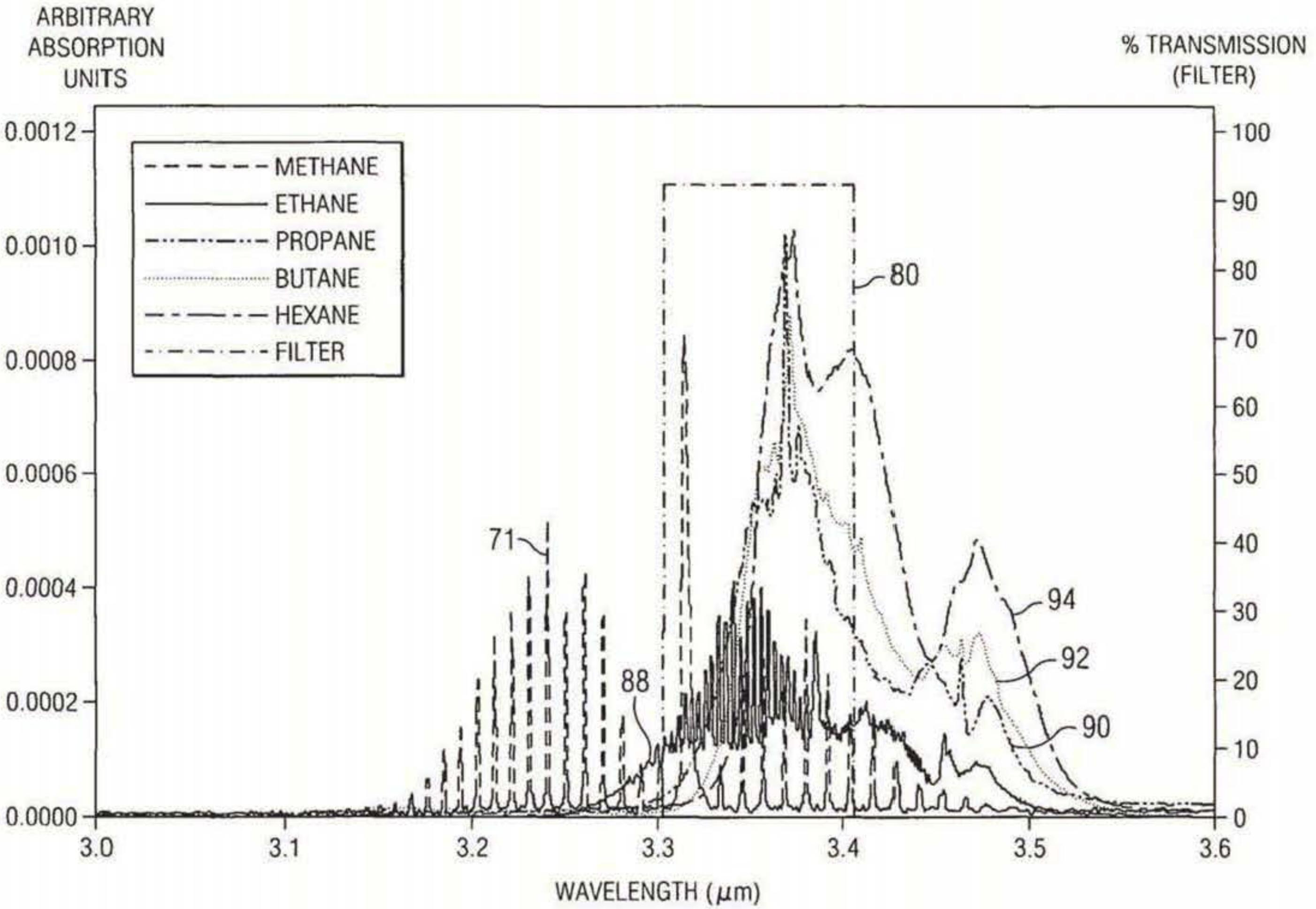
ARBITRARY ABSORPTION UNITS
% TRANSMISSION (FILTER)
0.0012
0.0010
0.0008
0.0006
0.0004
0.0002
0.0000
100
90
80
70
60
50
40
30
20
10
0
METHANE
ETHANE
PROPANE
BUTANE
HEXANE
FILTER
80
71
88
94
92
90
3.0
3.1
3.2
3.3
3.4
3.5
3.6
WAVELENGTH (μm)

FIG. 8

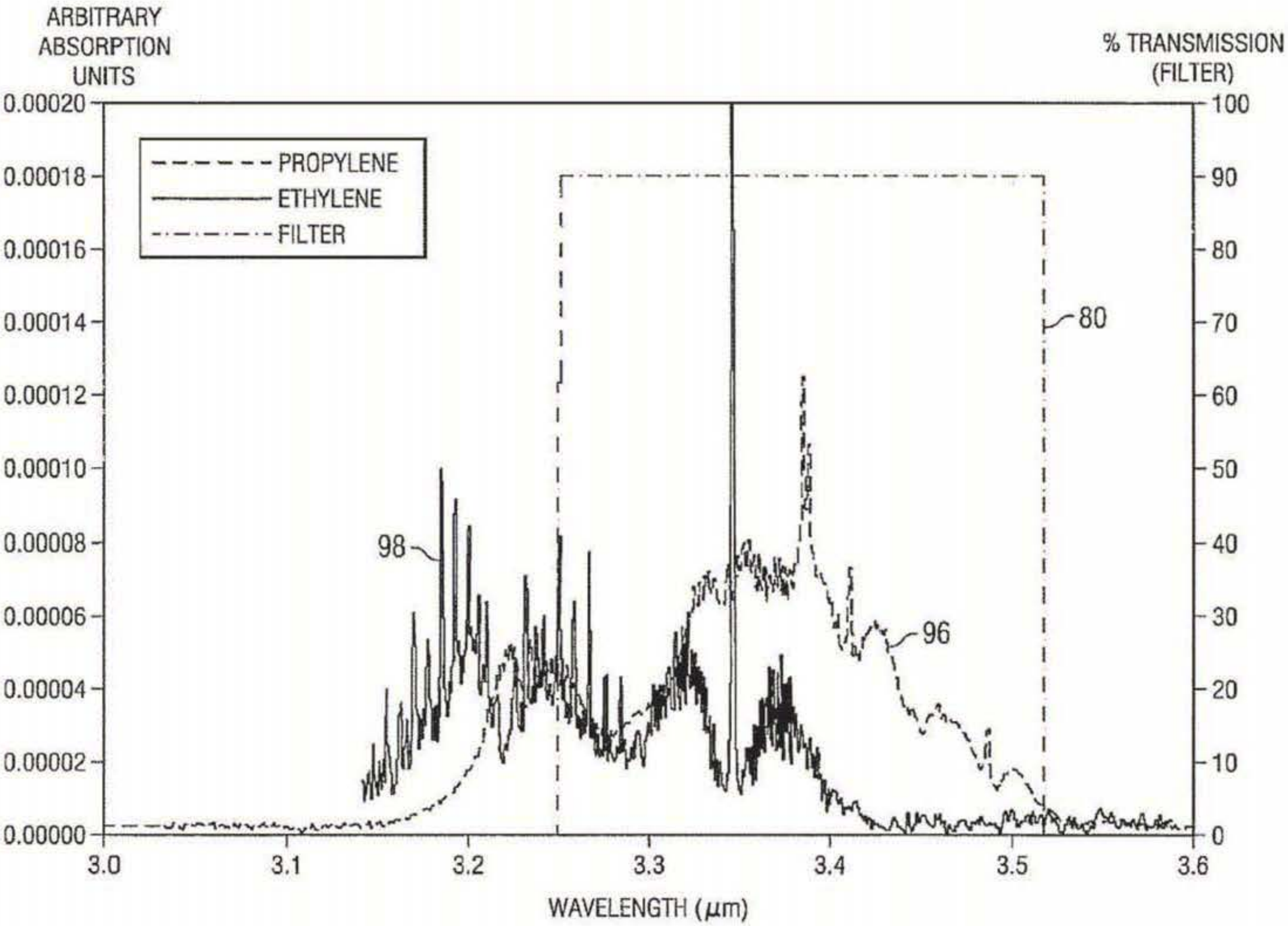
ARBITRARY ABSORPTION UNITS
% TRANSMISSION (FILTER)
PROPYLENE
ETHYLENE
FILTER
0.00020
0.00018
0.00016
0.00014
0.00012
0.00010
0.00008
0.00006
0.00004
0.00002
0.00000
100
90
80
70
60
50
40
30
20
10
0
80
98
96
3.0
3.1
3.2
3.3
3.4
3.5
3.6
WAVELENGTH (μm)

FIG. 9

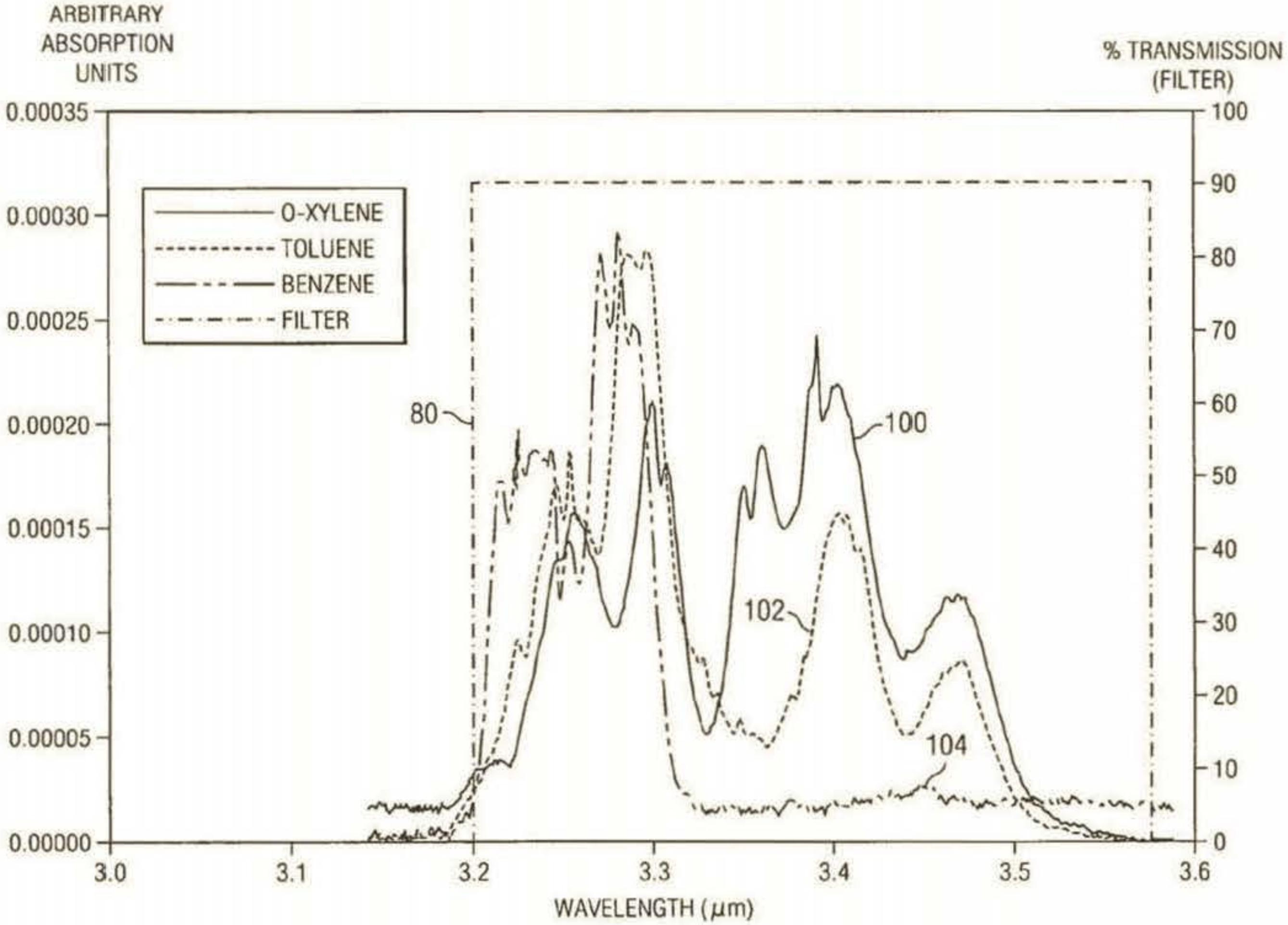
ARBITRARY ABSORPTION UNITS
0.00035
0.00030
0.00025
0.00020
0.00015
0.00010
0.00005
0.00000
% TRANSMISSION (FILTER)
100
90
80
70
60
50
40
30
20
10
0
O-XYLENE
TOLUENE
BENZENE
FILTER
80
100
102
104
3.0
3.1
3.2
3.3
3.4
3.5
3.6
WAVELENGTH (μm)

FIG. 10

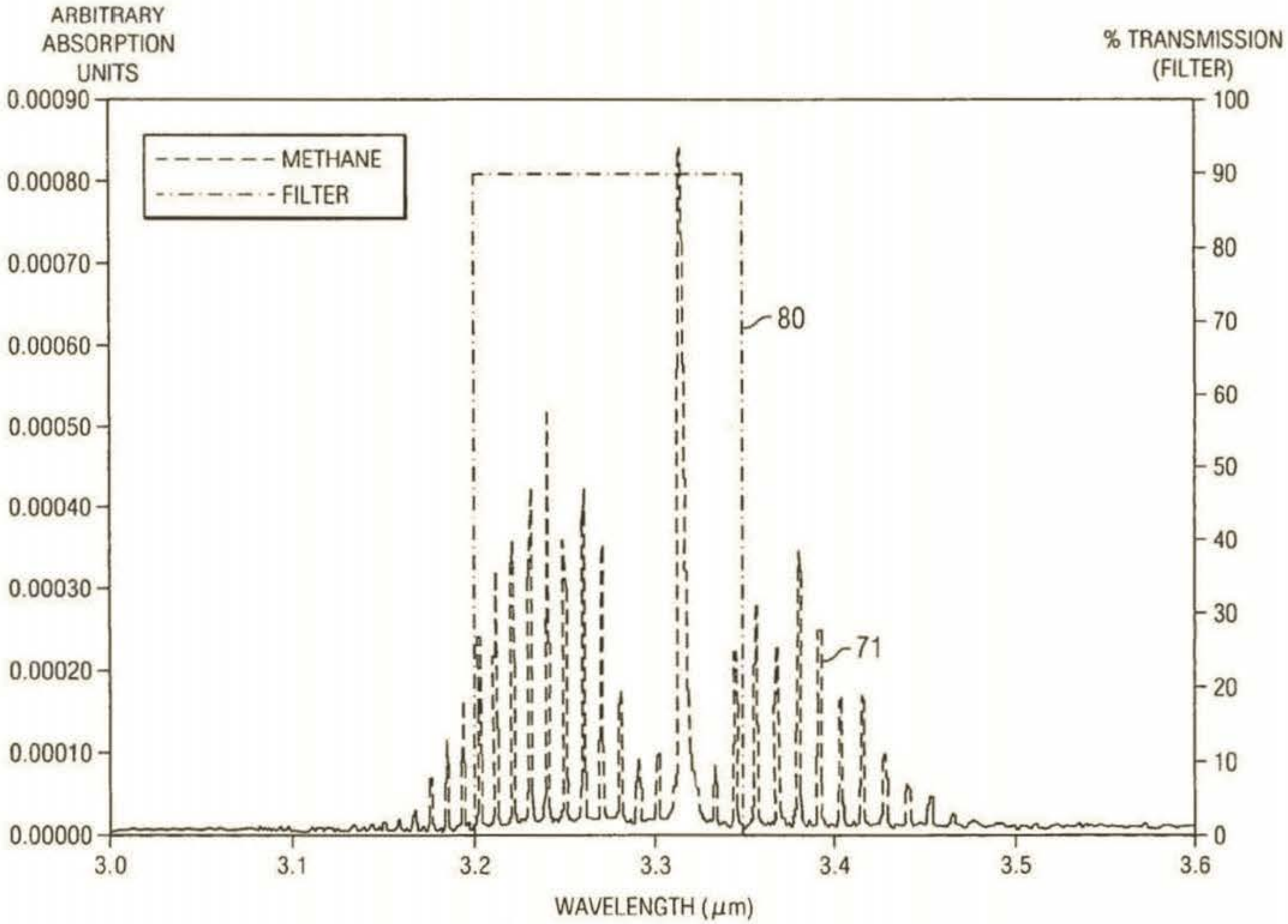
ARBITRARY ABSORPTION UNITS
% TRANSMISSION (FILTER)
METHANE
FILTER
0.00090
0.00080
0.00070
0.00060
0.00050
0.00040
0.00030
0.00020
0.00010
0.00000
100
90
80
70
60
50
40
30
20
10
0
80
71
3.0
3.1
3.2
3.3
3.4
3.5
3.6
WAVELENGTH (μm)

FIG. 11

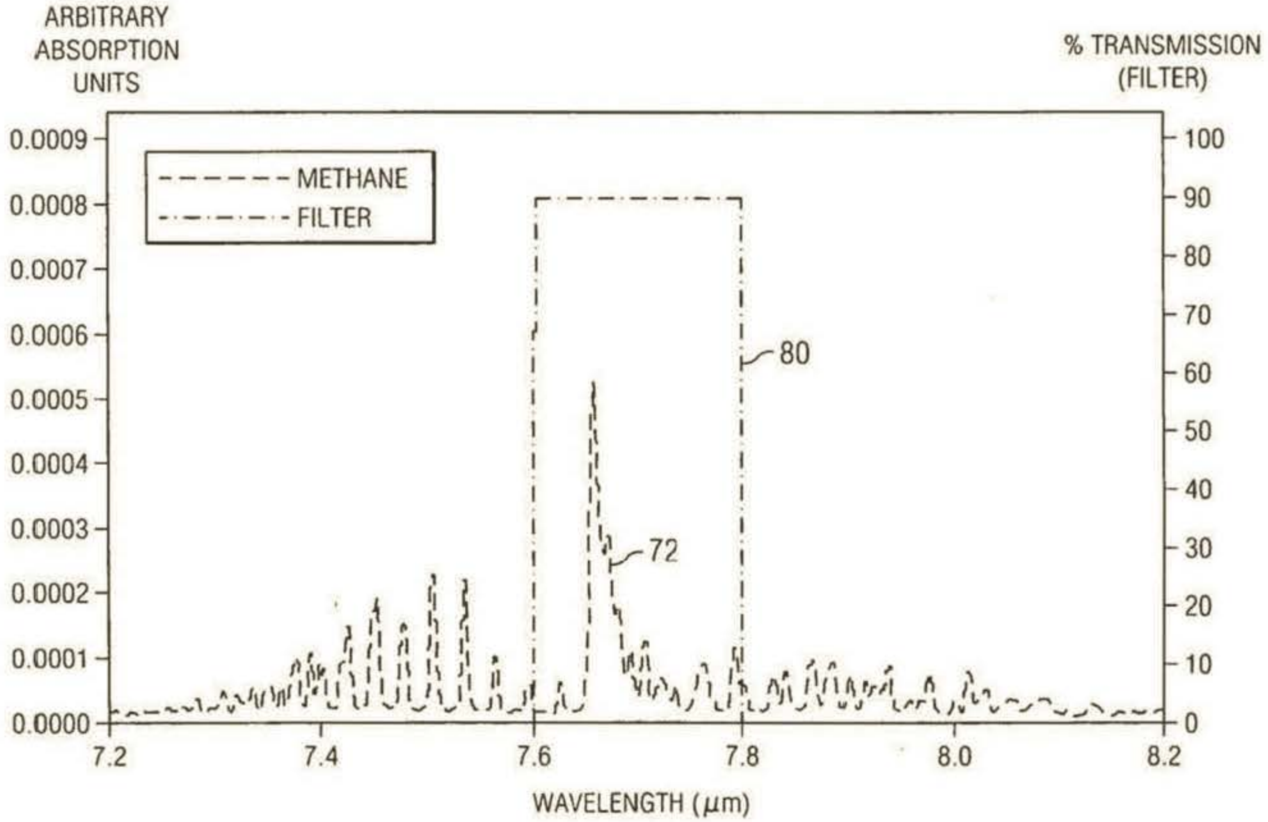
ARBITRARY
ABSORPTION
UNITS
% TRANSMISSION
(FILTER)
METHANE
FILTER
0.0009
0.0008
0.0007
0.0006
0.0005
0.0004
0.0003
0.0002
0.0001
0.0000
100
90
80
70
60
50
40
30
20
10
0
80
72
7.2
7.4
7.6
7.8
8.0
8.2
WAVELENGTH (μm)

FIG. 12

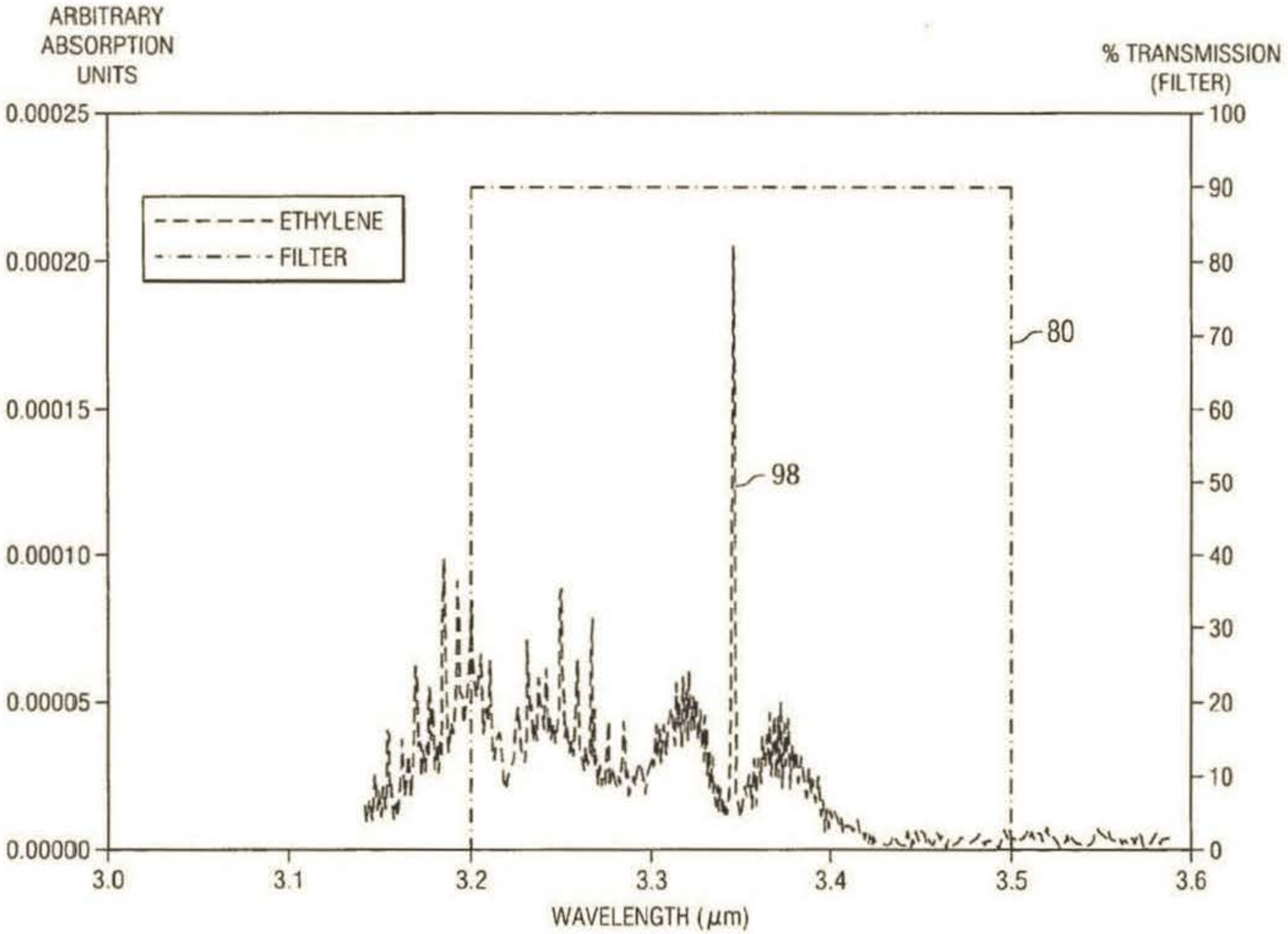
ARBITRARY ABSORPTION UNITS
% TRANSMISSION (FILTER)
0.00025
0.00020
0.00015
0.00010
0.00005
0.00000
100
90
80
70
60
50
40
30
20
10
0
ETHYLENE
FILTER
80
98
3.0
3.1
3.2
3.3
3.4
3.5
3.6
WAVELENGTH (μm)

FIG. 13

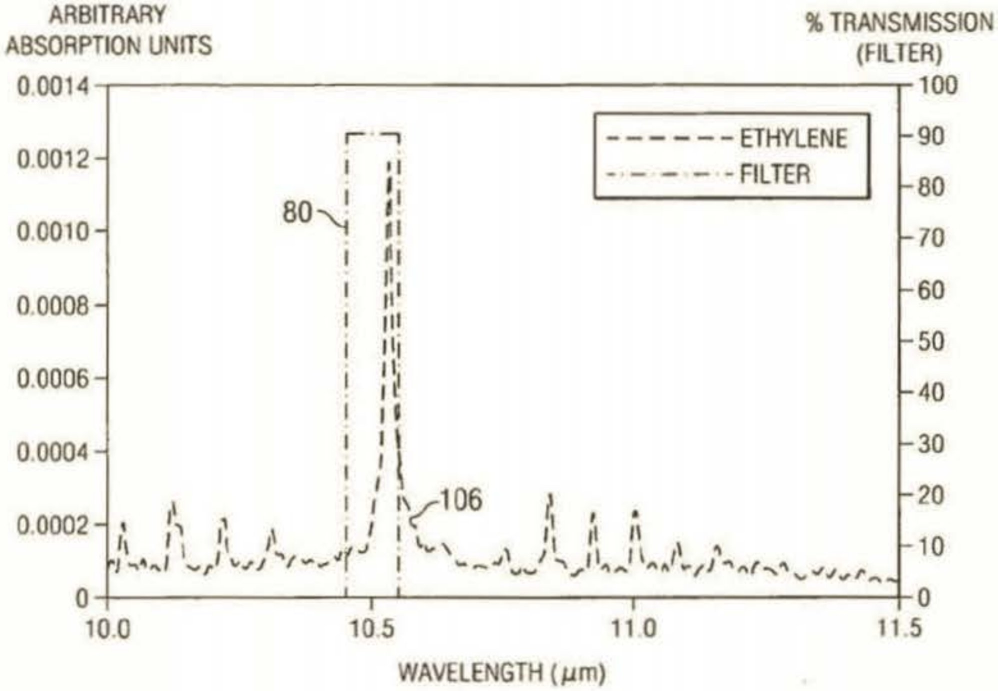
ARBITRARY ABSORPTION UNITS
% TRANSMISSION (FILTER)
0.0014
0.0012
0.0010
0.0008
0.0006
0.0004
0.0002
0
100
90
80
70
60
50
40
30
20
10
0
ETHYLENE
FILTER
80
106
10.0
10.5
11.0
11.5
WAVELENGTH (μm)

FIG. 14

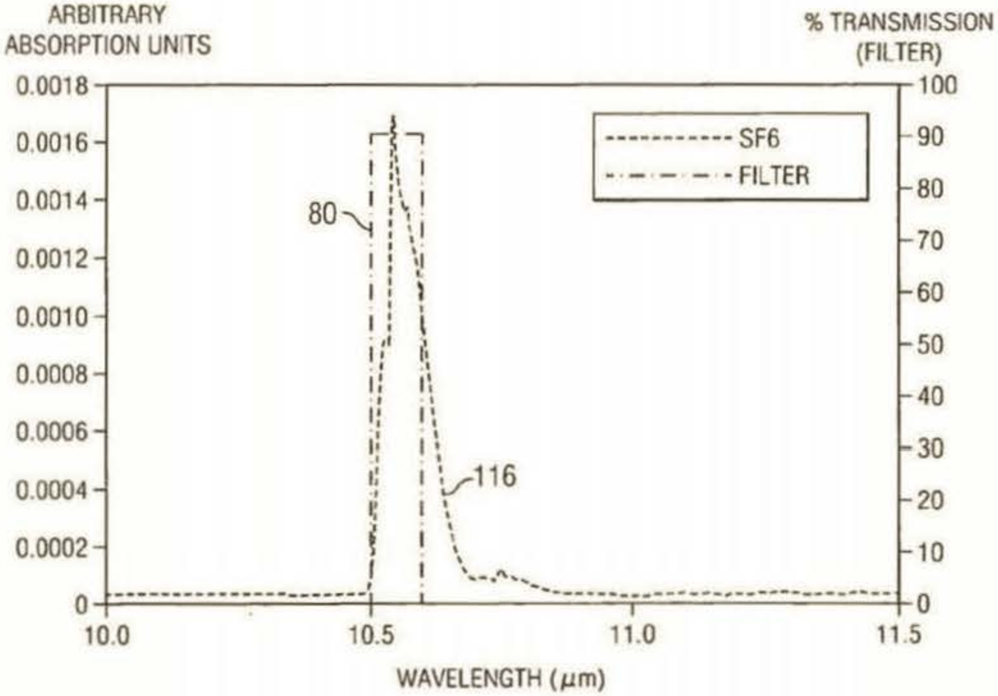
ARBITRARY ABSORPTION UNITS
% TRANSMISSION (FILTER)
0.0018
0.0016
0.0014
0.0012
0.0010
0.0008
0.0006
0.0004
0.0002
0
100
90
80
70
60
50
40
30
20
10
0
SF6
FILTER
80
116
10.0
10.5
11.0
11.5
WAVELENGTH (μm)

FIG. 19

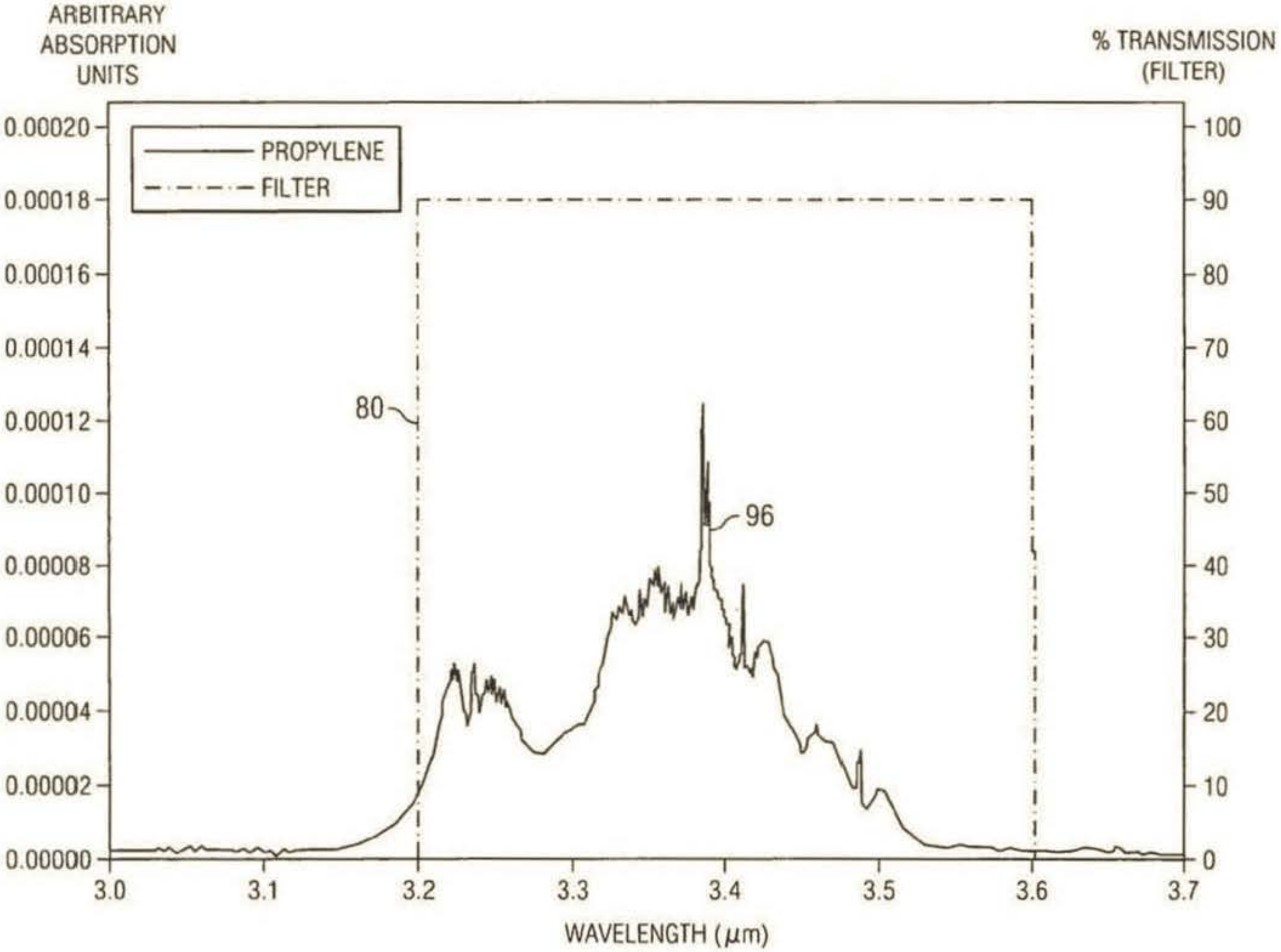
ARBITRARY ABSORPTION UNITS
% TRANSMISSION (FILTER)
PROPYLENE
FILTER
0.00020
0.00018
0.00016
0.00014
0.00012
0.00010
0.00008
0.00006
0.00004
0.00002
0.00000
100
90
80
70
60
50
40
30
20
10
0
80
96
3.0
3.1
3.2
3.3
3.4
3.5
3.6
3.7
WAVELENGTH (μm)

FIG. 15

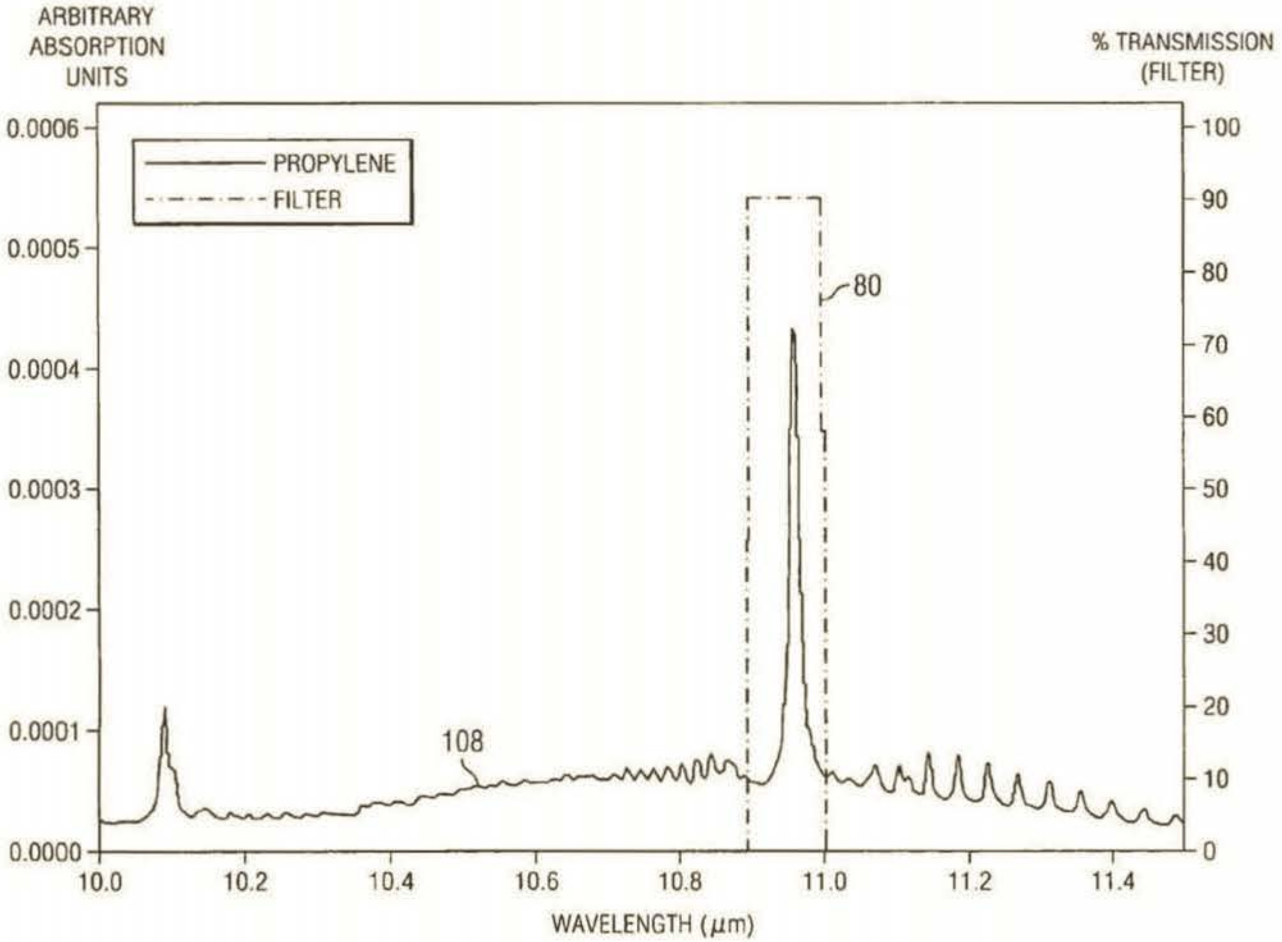
ARBITRARY ABSORPTION UNITS
% TRANSMISSION (FILTER)
PROPYLENE
FILTER
0.0006
0.0005
0.0004
0.0003
0.0002
0.0001
0.0000
100
90
80
70
60
50
40
30
20
10
0
80
108
10.0
10.2
10.4
10.6
10.8
11.0
11.2
11.4
WAVELENGTH (μm)

FIG. 16

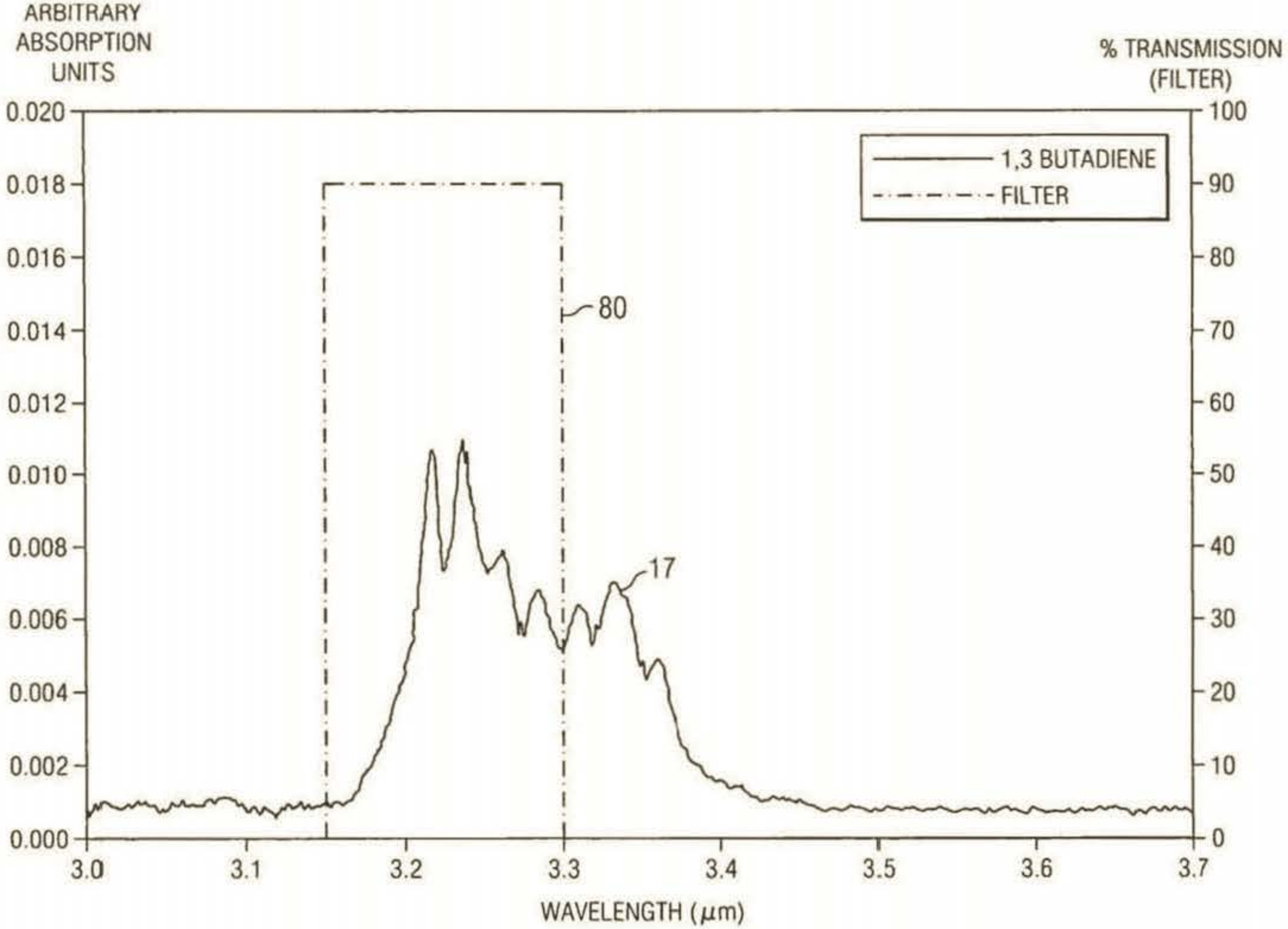
ARBITRARY ABSORPTION UNITS
% TRANSMISSION (FILTER)
0.020
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
100
90
80
70
60
50
40
30
20
10
0
1,3 BUTADIENE
FILTER
80
17
3.0
3.1
3.2
3.3
3.4
3.5
3.6
3.7
WAVELENGTH (μm)

FIG. 17

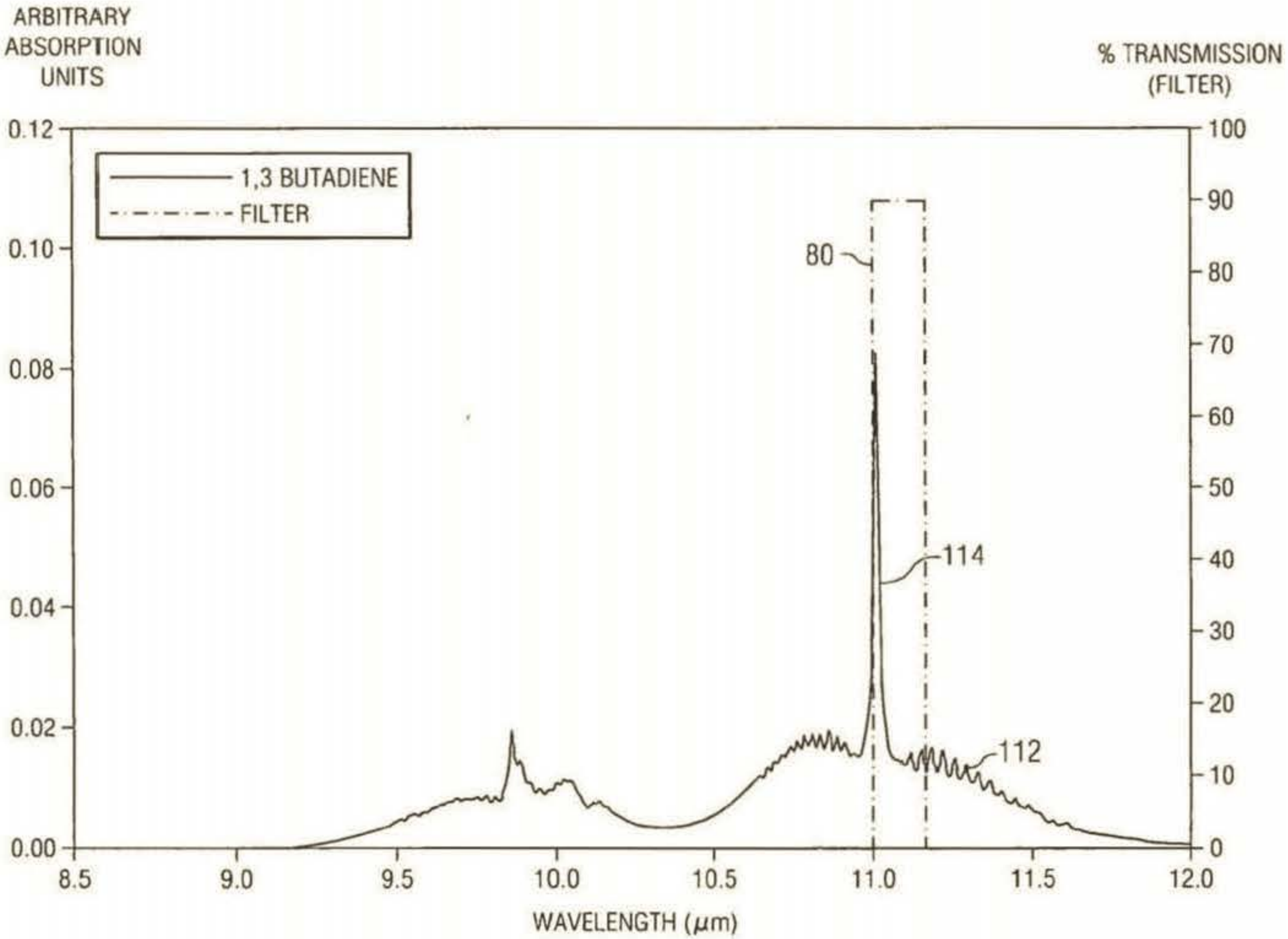
ARBITRARY ABSORPTION UNITS
% TRANSMISSION (FILTER)
1,3 BUTADIENE
FILTER
0.12
0.10
0.08
0.06
0.04
0.02
0.00
100
90
80
70
60
50
40
30
20
10
0
8.5
9.0
9.5
10.0
10.5
11.0
11.5
12.0
WAVELENGTH (μm)
80
114
112

FIG. 18

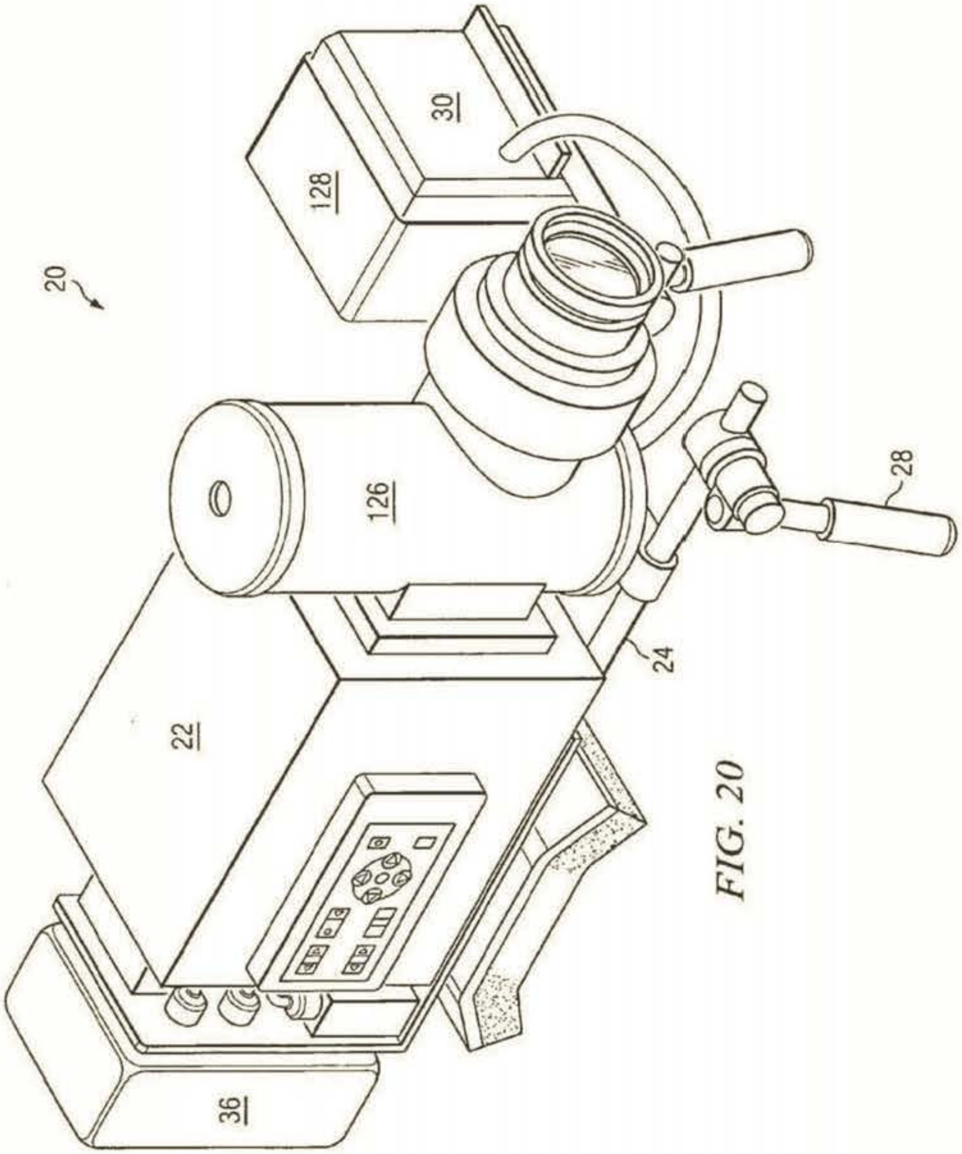

FIG. 20

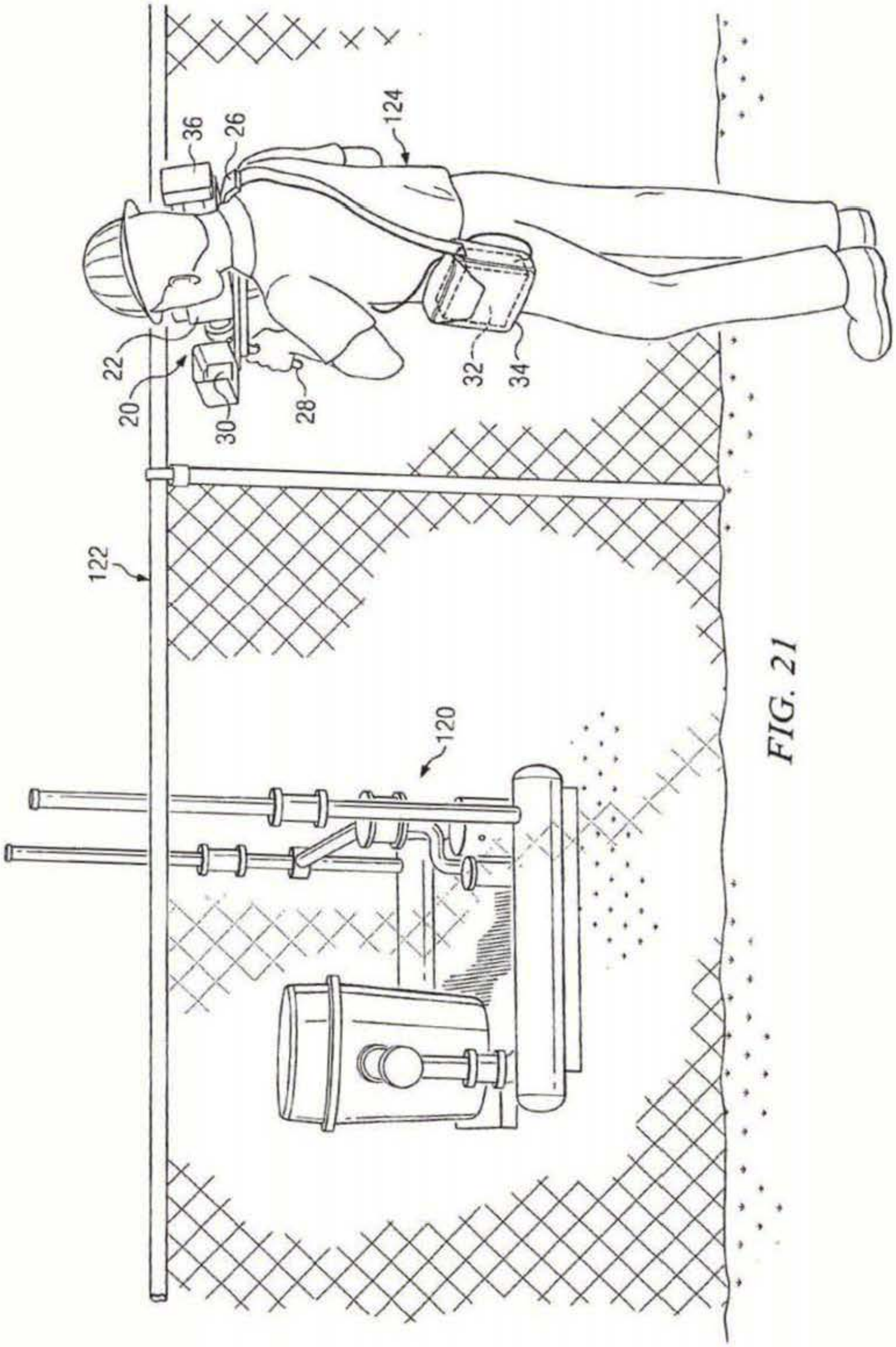

FIG. 21

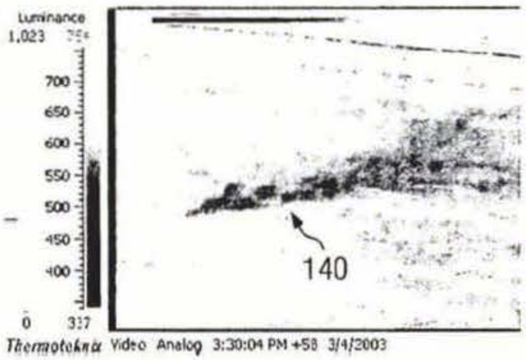

FIG. 23A

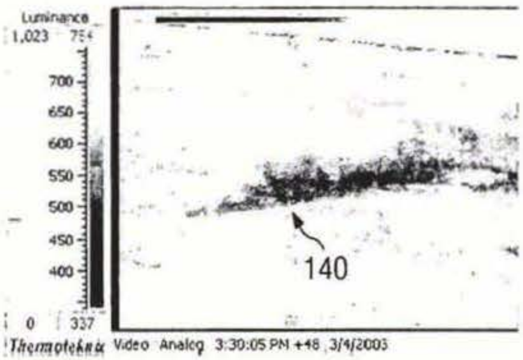

FIG. 23B

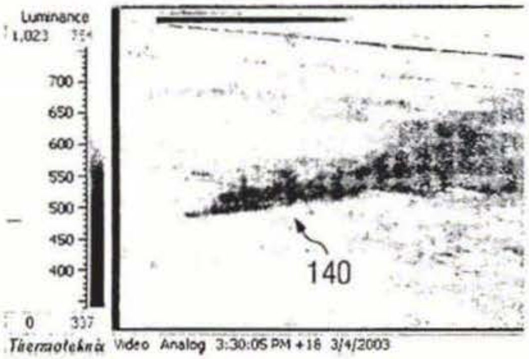

FIG. 23C

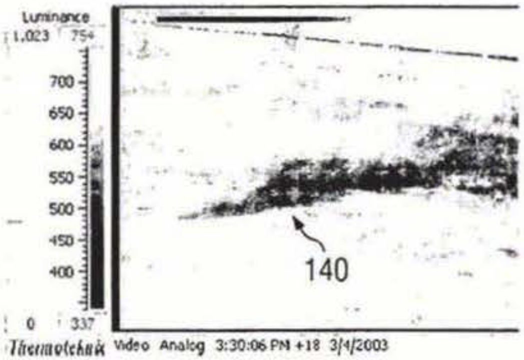

FIG. 23D

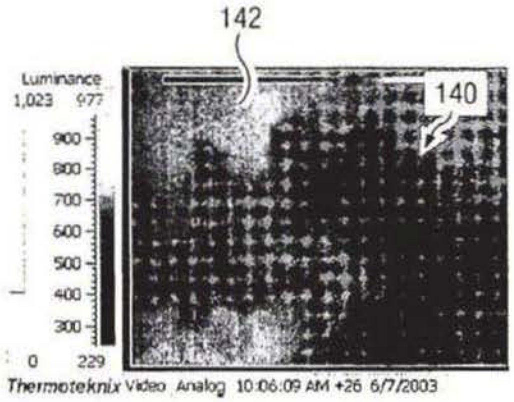

FIG. 24A

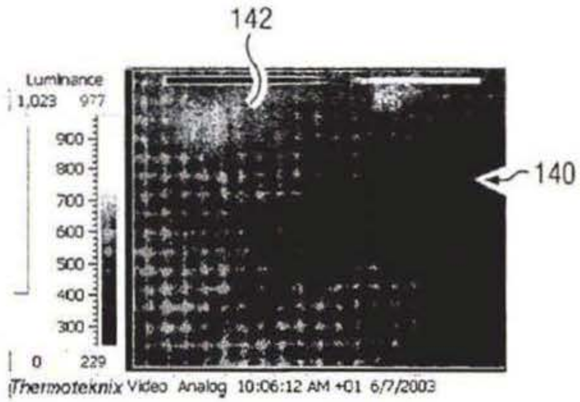

FIG. 24C

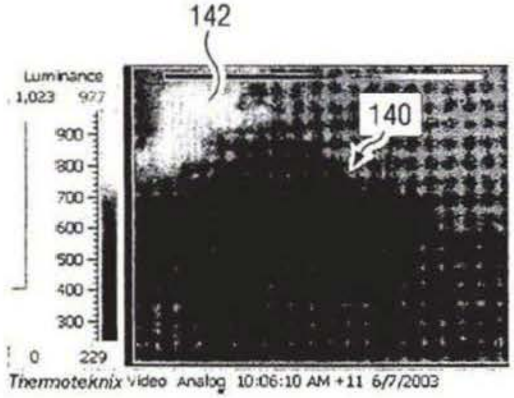

FIG. 24B

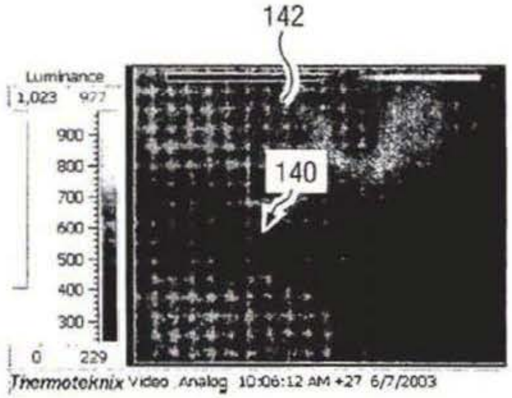

FIG. 24D

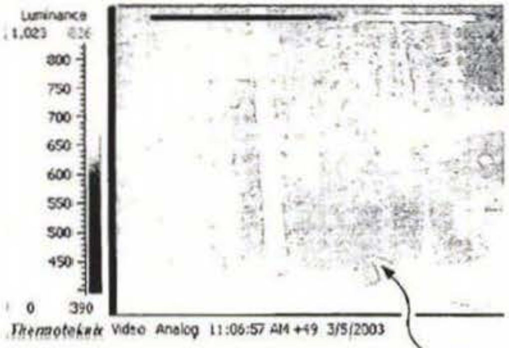

FIG. 25A

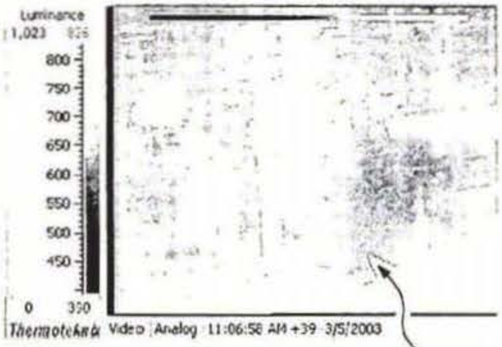

FIG. 25B

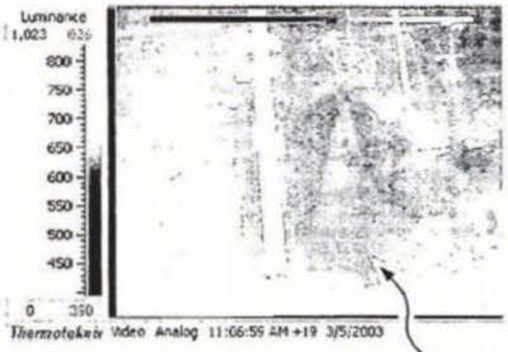

FIG. 25C

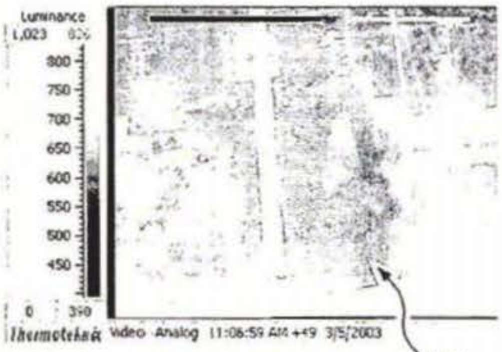

FIG. 25D

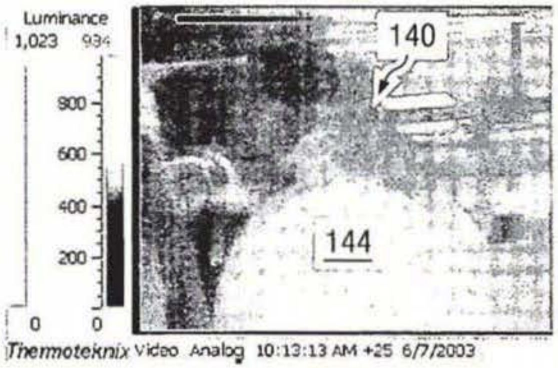

FIG. 26

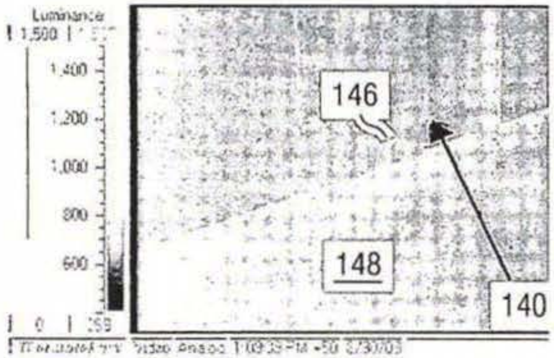

FIG. 27

FIG. 28A

FIG. 28B

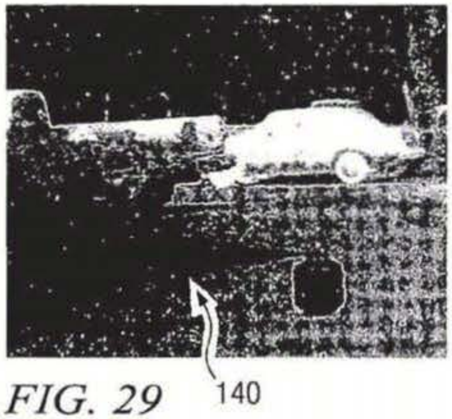

FIG. 29

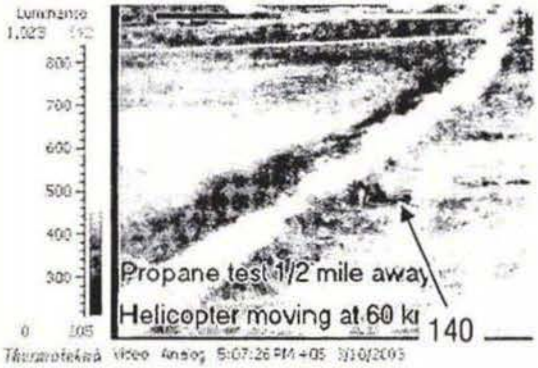

FIG. 31A

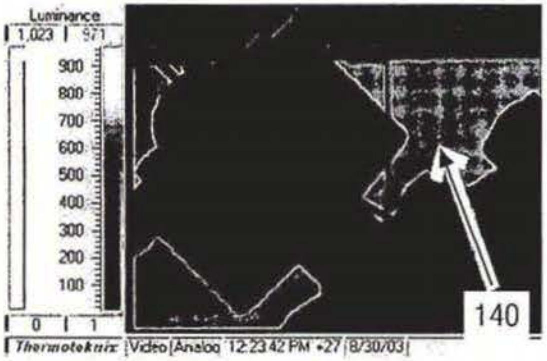

FIG. 30

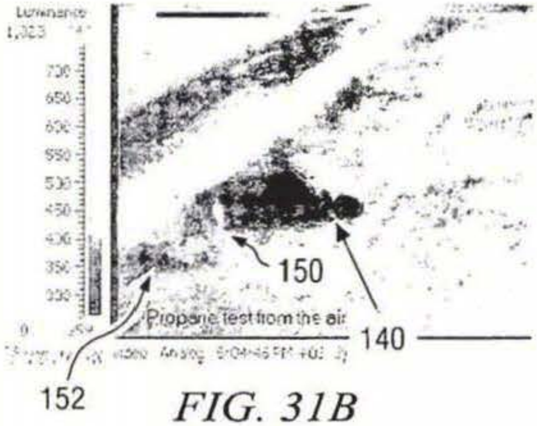

FIG. 31B

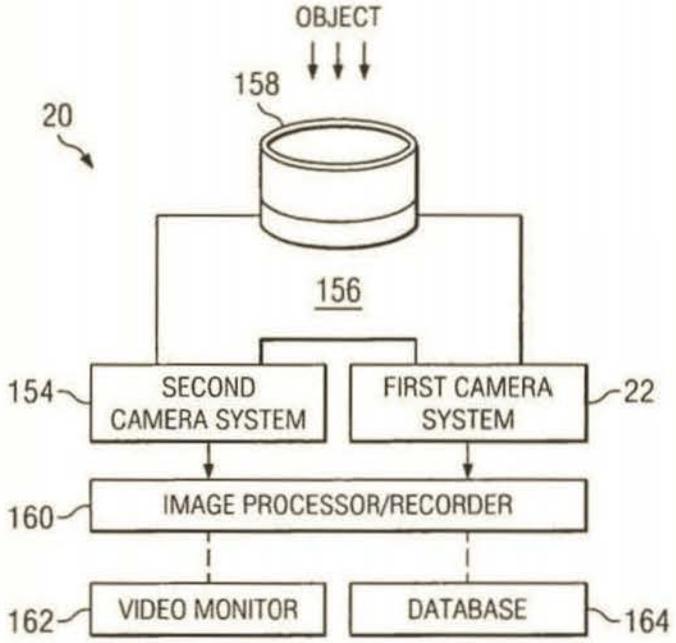
OBJECT
158
20
156
154
SECOND CAMERA SYSTEM
FIRST CAMERA SYSTEM
22
160
IMAGE PROCESSOR/RECORDER
162
VIDEO MONITOR
DATABASE
164

FIG. 32

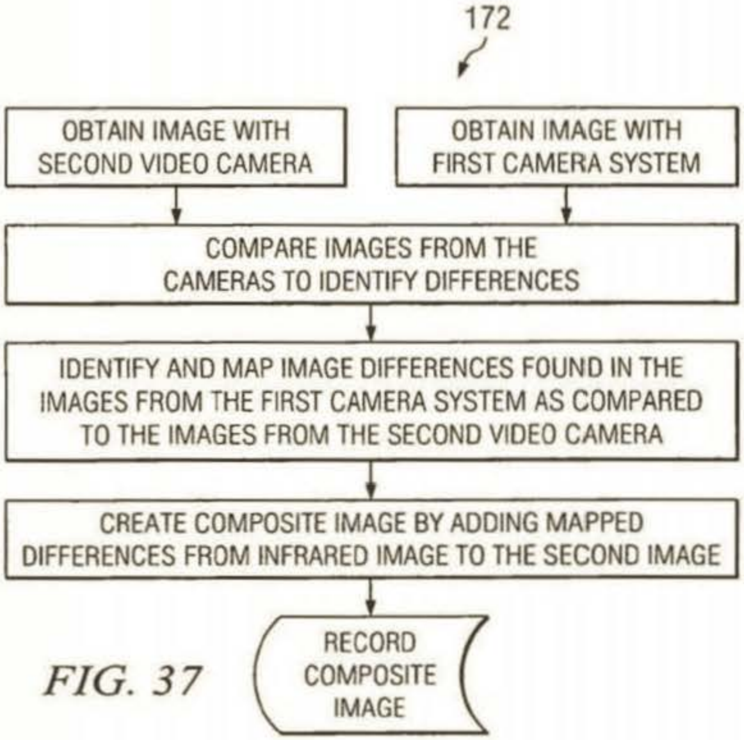
172
OBTAIN IMAGE WITH SECOND VIDEO CAMERA
OBTAIN IMAGE WITH FIRST CAMERA SYSTEM
COMPARE IMAGES FROM THE CAMERAS TO IDENTIFY DIFFERENCES
IDENTIFY AND MAP IMAGE DIFFERENCES FOUND IN THE IMAGES FROM THE FIRST CAMERA SYSTEM AS COMPARED TO THE IMAGES FROM THE SECOND VIDEO CAMERA
CREATE COMPOSITE IMAGE BY ADDING MAPPED DIFFERENCES FROM INFRARED IMAGE TO THE SECOND IMAGE
RECORD COMPOSITE IMAGE

FIG. 37

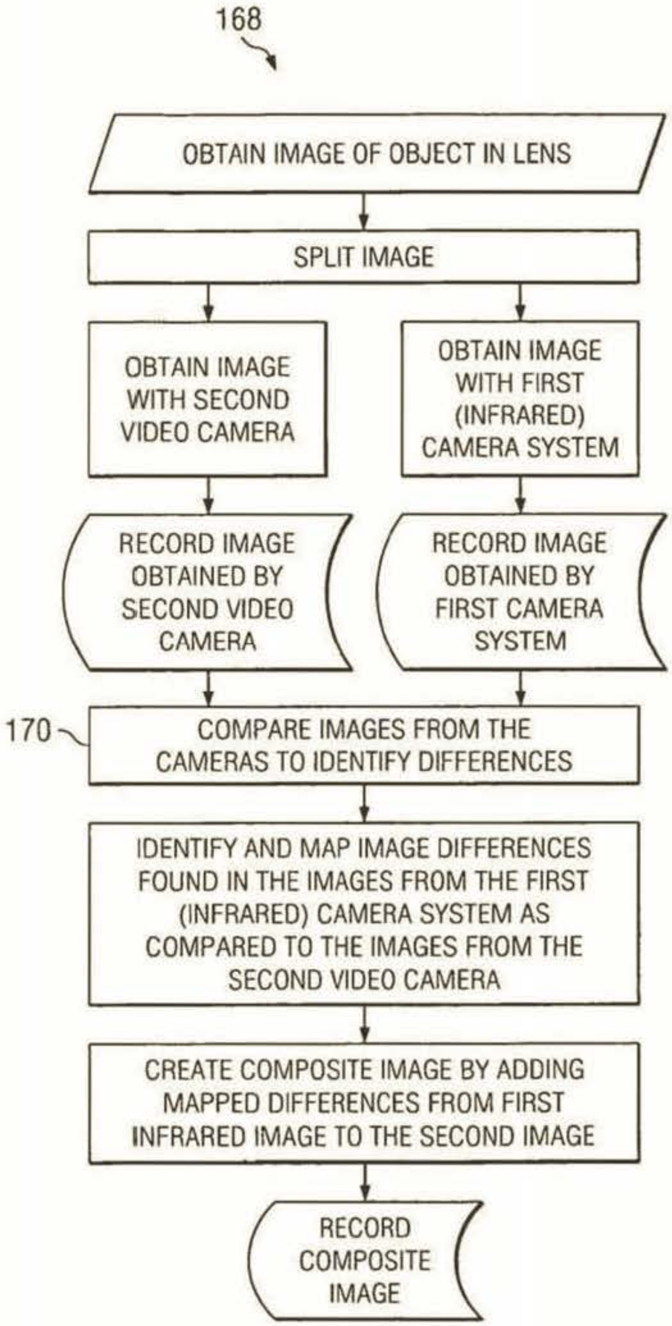
168
OBTAIN IMAGE OF OBJECT IN LENS
SPLIT IMAGE
OBTAIN IMAGE WITH SECOND VIDEO CAMERA
OBTAIN IMAGE WITH FIRST (INFRARED) CAMERA SYSTEM
RECORD IMAGE OBTAINED BY SECOND VIDEO CAMERA
RECORD IMAGE OBTAINED BY FIRST CAMERA SYSTEM
170
COMPARE IMAGES FROM THE CAMERAS TO IDENTIFY DIFFERENCES
IDENTIFY AND MAP IMAGE DIFFERENCES FOUND IN THE IMAGES FROM THE FIRST (INFRARED) CAMERA SYSTEM AS COMPARED TO THE IMAGES FROM THE SECOND VIDEO CAMERA
CREATE COMPOSITE IMAGE BY ADDING MAPPED DIFFERENCES FROM FIRST INFRARED IMAGE TO THE SECOND IMAGE
RECORD COMPOSITE IMAGE

FIG. 33

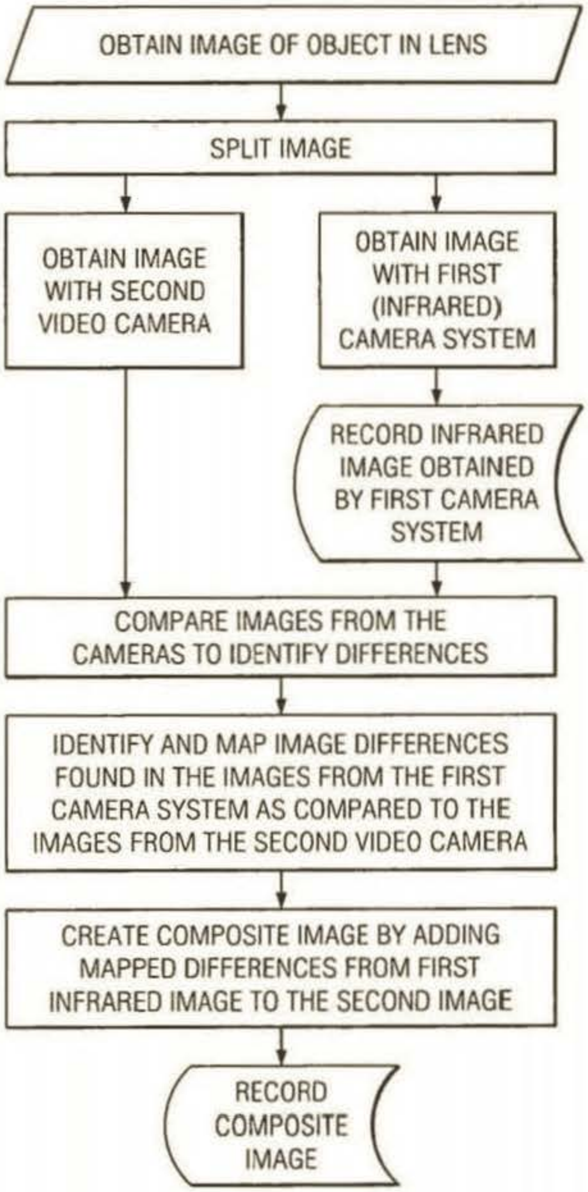
OBTAIN IMAGE OF OBJECT IN LENS
SPLIT IMAGE
OBTAIN IMAGE WITH SECOND VIDEO CAMERA
OBTAIN IMAGE WITH FIRST (INFRARED) CAMERA SYSTEM
RECORD INFRARED IMAGE OBTAINED BY FIRST CAMERA SYSTEM
COMPARE IMAGES FROM THE CAMERAS TO IDENTIFY DIFFERENCES
IDENTIFY AND MAP IMAGE DIFFERENCES FOUND IN THE IMAGES FROM THE FIRST CAMERA SYSTEM AS COMPARED TO THE IMAGES FROM THE SECOND VIDEO CAMERA
CREATE COMPOSITE IMAGE BY ADDING MAPPED DIFFERENCES FROM FIRST INFRARED IMAGE TO THE SECOND IMAGE
RECORD COMPOSITE IMAGE

FIG. 34

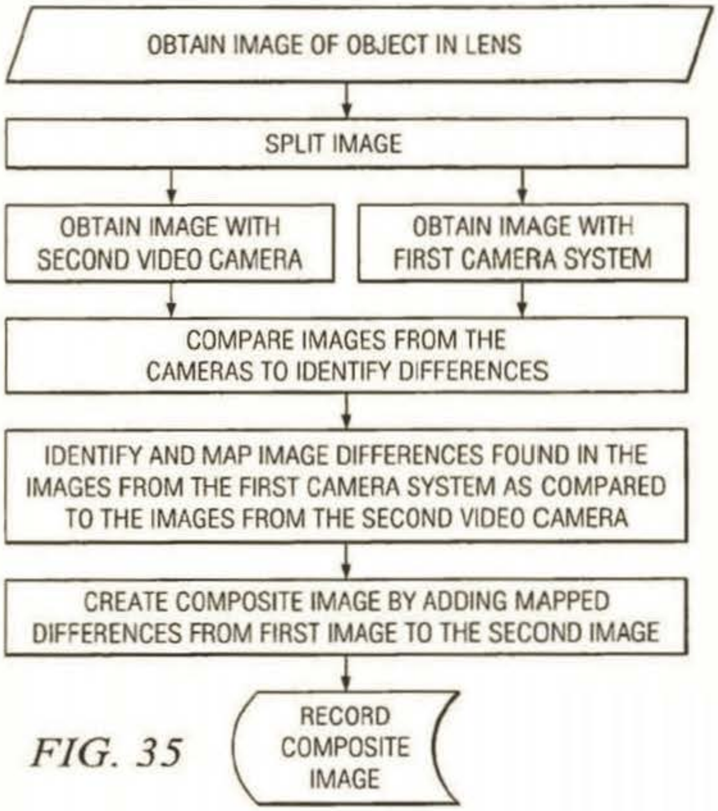
OBTAIN IMAGE OF OBJECT IN LENS
SPLIT IMAGE
OBTAIN IMAGE WITH SECOND VIDEO CAMERA
OBTAIN IMAGE WITH FIRST CAMERA SYSTEM
COMPARE IMAGES FROM THE CAMERAS TO IDENTIFY DIFFERENCES
IDENTIFY AND MAP IMAGE DIFFERENCES FOUND IN THE IMAGES FROM THE FIRST CAMERA SYSTEM AS COMPARED TO THE IMAGES FROM THE SECOND VIDEO CAMERA
CREATE COMPOSITE IMAGE BY ADDING MAPPED DIFFERENCES FROM FIRST IMAGE TO THE SECOND IMAGE
RECORD COMPOSITE IMAGE

FIG. 35

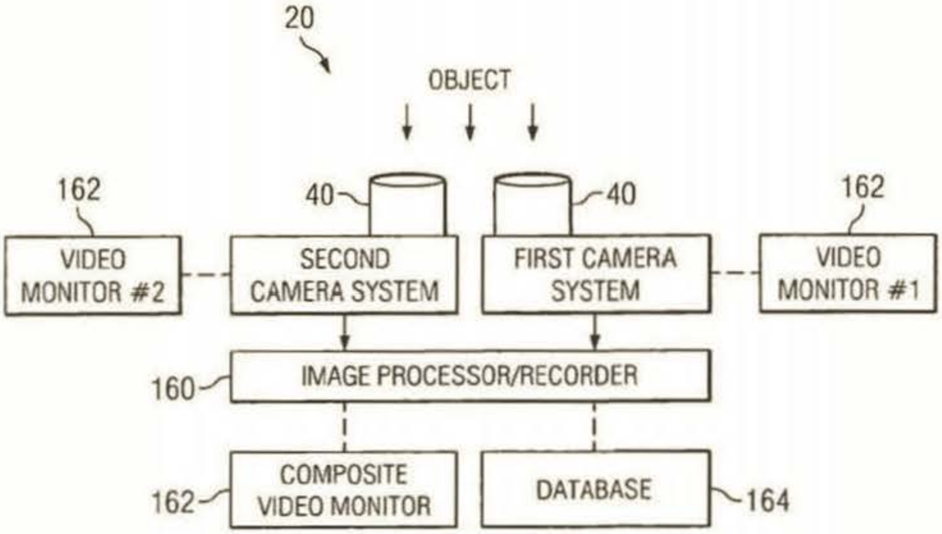
20
OBJECT
162
40
40
162
VIDEO MONITOR #2
SECOND CAMERA SYSTEM
FIRST CAMERA SYSTEM
VIDEO MONITOR #1
160
IMAGE PROCESSOR/RECORDER
162
COMPOSITE VIDEO MONITOR
DATABASE
164

FIG. 36

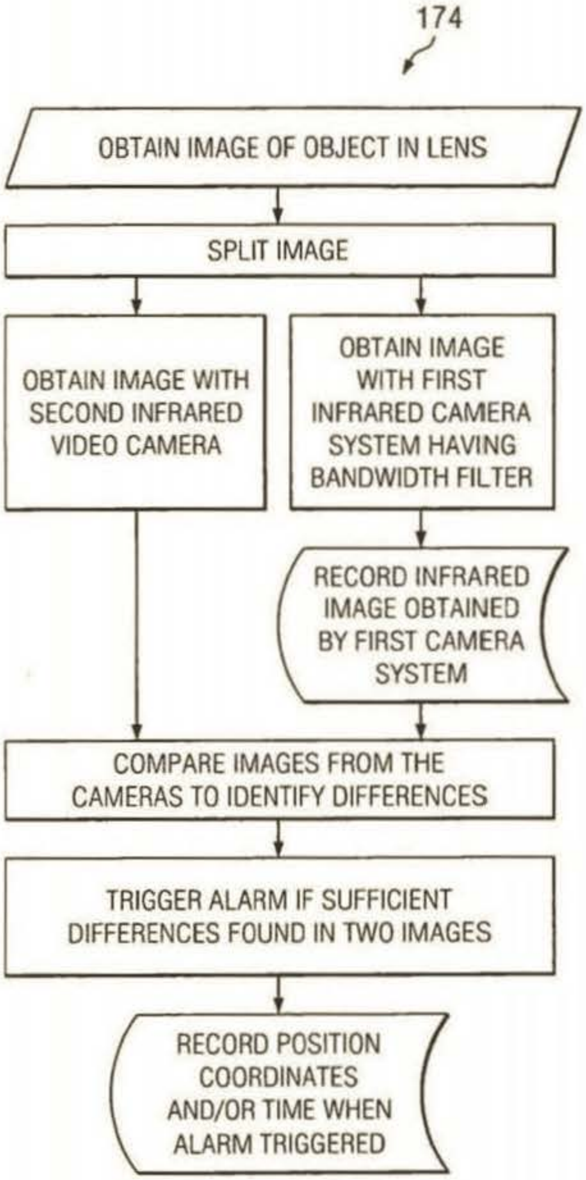
174
OBTAIN IMAGE OF OBJECT IN LENS
SPLIT IMAGE
OBTAIN IMAGE WITH SECOND INFRARED VIDEO CAMERA
OBTAIN IMAGE WITH FIRST INFRARED CAMERA SYSTEM HAVING BANDWIDTH FILTER
RECORD INFRARED IMAGE OBTAINED BY FIRST CAMERA SYSTEM
COMPARE IMAGES FROM THE CAMERAS TO IDENTIFY DIFFERENCES
TRIGGER ALARM IF SUFFICIENT DIFFERENCES FOUND IN TWO IMAGES
RECORD POSITION COORDINATES AND/OR TIME WHEN ALARM TRIGGERED

FIG. 38

CHEMICAL LEAK INSPECTION SYSTEM

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 11/298,862, filed Dec. 10, 2005, entitled "Methods for Performing Inspections and Detecting Chemical Leaks Using an Infrared Camera System," which is a continuation of PCT International Application No. PCT/2004/012946, filed Apr. 26, 2004, entitled "Systems and Methods for Performing Inspections and Detecting Chemical Leaks Using an Infrared Camera System," which claims the benefit of U.S. Provisional Patent Application No. 60/477,994, filed Jun. 11, 2003, entitled "Method of Detecting Gas Leaks Using and Infrared Camera System," U.S. Provisional Patent Application No. 60/482,070, filed Jun. 23, 2003, entitled "Method of Detecting Gas Leaks Using and Infrared Camera System," and U.S. Provisional Patent Application No. 60/540,679, filed Jan. 30, 2004, entitled "Method of Detecting Gas Leaks Using an Infrared Camera System," all of which are incorporated herein by reference in their entirety for all purposes.

TECHNICAL FIELD

The present invention relates generally to visually detecting and identifying chemical, gas, and petroleum product leaks using an infrared (IR) camera system.

BACKGROUND

In the oil and gas business, in the petro-chemical industry, in processing plants, and for utility companies and utility providers, for example, often more time and money is spent trying to find leaks than fixing leaks. One of the biggest challenges is trying to find the leaks using conventional methods. Many conventional methods can simply miss a leak and not detect it if the detector is not properly positioned over or downwind of the leak. Also, many conventional methods are very time consuming and labor intensive, which leads to more expense. Hence, there is a great need for a faster, more accurate, and less expensive method of detecting such leaks.

Petroleum products, such as liquid, gas, and liquid/gas forms of hydrocarbon compounds (e.g., fossil fuels), are often transmitted or channeled in pipes. The conventional method of surveying lines for petroleum product leaks or for detecting petroleum product leaks in general is with a FLAME-PACK ionizer detector (also sometimes referred to as a "sniffer" device). Another recently developed system uses an active infrared system (having a transmitting infrared source and a receiving sensor) for detecting petroleum product fumes. However, such systems require that the detector be within the stream or plume of the petroleum product leak. These tests merely detect the presence of petroleum product fumes at or upwind of the detector. They do not provide a visual image of the leak. Also, these prior testing methods require the detector to be in the immediate proximity of the leak, which may be dangerous and/or difficult for the inspector.

Prior infrared systems designed for evaluating rocket fumes, for example, would provide an unfocused and fuzzy image, in which it was difficult to make out background objects. For example, using an infrared camera that images a broad range of infrared wavelengths (e.g., 3-5 microns) typically will not be useful in detecting small leaks. One system uses a variable filter that scans through different bandwidths in an attempt to identify the bandwidth of the strongest intensity (as quantified by the system). The purpose of this system was an attempt to identify the chemical make-up of a rocket exhaust based on the wavelength at which the intensity was greatest for the rocket plume. However, this system is not designed to provide a focused visual image to view the rocket exhaust.

Others have attempted to visualize petroleum product leaks using infrared cameras using a "warm" filter setup and/or an active infrared camera system. A warm filter setup is one in which a filter is used to limit the wavelengths of light that reach the infrared sensor, but the filter is not in a cooled or refrigerated portion of the camera, if the camera even has a refrigerated portion. Such systems have not been able to provide a focused image capable of quickly and easily detecting small leaks, nor being capable of detecting leaks from a distance (e.g., from a helicopter passing over a line). Other systems are active and require a laser beam to be projected through the area under inspection in order to detect the presence of a chemical emanating from a component. However, with such systems, typically the narrow laser beam must cross the flow stream for the leak to be detected. Hence, a leak may be missed if the laser beam does not cross the path of the leak and such systems often are unable to reliably find small leaks. Hence, a need exists for a way to perform a visual inspection to find leaks with reliability and accuracy, while being faster and more cost effective than existing leak survey methods.

The U.S. Environmental Protection Agency (EPA) has proposed rules to allow visual inspections using infrared cameras in performing leak inspection surveys. However, due to the lack of detection abilities and poor performance demonstrated by other prior and current systems, the EPA had not yet implemented such rules. Thus, even the EPA has been waiting for someone to provide a system or way of reliably and accurately detecting leaks of various sizes.

SUMMARY OF THE INVENTION

The problems and needs outlined above may be addressed by embodiments of the present invention. In accordance with one aspect of the present invention, a passive infrared camera system adapted to provide a visual image of a chemical emanating from a component having the chemical therein, is provided. The passive infrared camera system includes a lens, a refrigerated portion, and a refrigeration system. The refrigerated portion has therein an infrared sensor device and an optical bandpass filter. The infrared sensor device is adapted to capture an infrared image from the lens. The optical bandpass filter is located along an optical path between the lens and the infrared sensor device. At least part of a pass band for the optical bandpass filter is within an absorption band for the chemical. The refrigeration system is adapted to cool the refrigerated portion of the infrared camera system.

In accordance with another aspect of the present invention, a method of visually detecting a leak of a chemical emanating from a component, is provided. This method includes the following steps described in this paragraph. The order of the steps may vary, may be sequential, may overlap, may be in parallel, and combinations thereof. A passive infrared camera system is aimed towards the component. The passive infrared camera system includes a lens, a refrigerated portion, and a refrigeration system. The refrigerated portion includes therein an infrared sensor device and an optical bandpass filter. The optical bandpass filter is located along an optical path between the lens and the infrared sensor device. At least part of a pass band for the optical bandpass filter is within an absorption band for the chemical. The refrigeration system is adapted to cool the refrigerated portion. An infrared image is filtered with the optical bandpass filter. The infrared image is that of the leak of the chemical emanating from the component. After the infrared image passes through the lens and optical bandpass filter, the filtered infrared image of the leak is received with the infrared sensor device. The filtered infrared image received by the infrared sensor device is electronically processed to provide a visible image representing the filtered infrared image. The leak is visually identified based on the visible image representing the filtered infrared image provided by the infrared camera system.

The foregoing has outlined rather broadly features of the present invention in order that the detailed description of the invention that follows may be better understood. Additional features and advantages of the invention will be described hereinafter which form the subject of the claims of the invention. It should be appreciated by those skilled in the art that the conception and specific embodiment disclosed may be readily utilized as a basis for modifying or designing other structures or processes for carrying out the same purposes of the present invention. It should also be realized by those skilled in the art that such equivalent constructions do not depart from the spirit and scope of the invention as set forth in the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

The following is a brief description of the drawings, which illustrate exemplary embodiments of the present invention and in which:

FIG. **1** is perspective view of a chemical leak detection system of a first embodiment;

FIG. **2** is a schematic of the infrared camera system of the chemical leak detection system of FIG. **1**;

FIGS. **3**A-**3**D are absorption graphs for methane;

FIG. **4** is a transmission curve illustrating a pass band of an optical bandpass filter;

FIG. **5** is an absorption graph for a small set of alkane chemicals with the pass band of the first embodiment transposed thereon;

FIG. **6** is an absorption graph for a small set of alkene chemicals with the pass band of the first embodiment transposed thereon;

FIG. **7** is an absorption graph for a small set of aromatic chemicals with the pass band of the first embodiment transposed thereon;

FIG. **8** is an absorption graph for a small set of alkane chemicals with a schematic representation of a pass band for a second embodiment transposed thereon;

FIG. **9** is an absorption graph for a small set of alkene chemicals with a schematic representation of a pass band for a third embodiment transposed thereon;

FIG. **10** is an absorption graph for a small set of aromatic chemicals with a schematic representation of a pass band for a fourth embodiment transposed thereon;

FIG. **11** is an absorption graph for methane with a schematic representation of a pass band for a fifth embodiment transposed thereon;

FIG. **12** is an absorption graph for methane with a schematic representation of a pass band for a sixth embodiment transposed thereon;

FIG. **13** is an absorption graph for ethylene with a schematic representation of a pass band for a seventh embodiment transposed thereon;

FIG. **14** is an absorption graph for ethylene with a schematic representation of a pass band for an eighth embodiment transposed thereon;

FIG. **15** is an absorption graph for propylene with a schematic representation of a pass band for a ninth embodiment transposed thereon;

FIG. **16** is an absorption graph for propylene with a schematic representation of a pass band for a tenth embodiment transposed thereon;

FIG. **17** is an absorption graph for 1,3 butadiene with a schematic representation of a pass band for an eleventh embodiment transposed thereon;

FIG. **18** is an absorption graph for 1,3 butadiene with a schematic representation of a pass band for a twelfth embodiment transposed thereon;

FIG. **19** is an absorption graph for sulfur hexafluorine with a schematic representation of a pass band for a thirteenth embodiment transposed thereon;

FIG. **20** is perspective view of a chemical leak detection system of a fourteenth embodiment;

FIG. **21** shows an inspector using an embodiment of the present invention;

FIG. **22** illustrates a use of an embodiment of the present invention to inspect multiple yards from a single yard;

FIGS. **23**A-**31**B are example images obtained using an embodiment of the present invention;

FIG. **32** is a schematic of a dual camera embodiment of the present invention;

FIGS. **33**-**35** are flowcharts illustrating methods of using a dual camera embodiment of the present invention;

FIG. **36** is a schematic of another dual camera embodiment of the present invention; and

FIGS. **37** and **38** are flowcharts illustrating more methods of using a dual camera embodiment of the present invention.

DETAILED DESCRIPTION OF THE ILLUSTRATIVE EMBODIMENTS

Referring now to the drawings, wherein like reference numbers are used herein to designate like or similar elements throughout the various views, illustrative embodiments of the present invention are shown and described. The figures are not necessarily drawn to scale, and in some instances the drawings have been exaggerated and/or simplified in places for illustrative purposes only. One of ordinary skill in the art will appreciate the many possible applications and variations of the present invention based on the following illustrative embodiments of the present invention.

FIG. **1** shows a chemical leak inspection system **20** in accordance with a first embodiment of the present invention. The chemical leak inspection system **20** of the first embodiment includes a passive infrared camera system **22**. The passive infrared camera system **22** of the first embodiment is adapted to provide a visible image representing a filtered infrared image of a chemical emanating (e.g., leaking) from a component having the chemical therein, as discussed in more detail below.

As shown in FIG. **1**, the infrared camera system **22** may be mounted on a frame **24**. A shoulder-rest portion **26** and handles **28** may be attached to the frame **24**, as shown in FIG. **1**. The shoulder-rest portion **26** and the handles **28** aid in holding the system **20** during an inspection (see e.g., FIG. **21** discussed below). Typically during an inspection using this system **20**, an inspector will walk around various components while carrying the system **20** on his shoulder and aiming the system **20** toward the components to look for leaks. In other embodiments, however, the camera system **22** may be handled or carried in other ways (e.g., by hand, from a vehicle, on a vehicle, on a tripod, on a gyro-stabilized platform, by a harness, etc.). Also, as discussed further below, inspections using an embodiment of the present invention may be performed from a vehicle (moving and not moving).

The leak inspection system **20** of the first embodiment also has a flat-panel display screen **30** (e.g., LCD display) electrically coupled to the infrared camera system **22** (see e.g., FIG. **1**). The visible images (representing the filtered infrared images) provided by the camera system **22** may be displayed on the display screen **30** during an inspection. The system **20** preferably includes a video recording device **32** (not shown in FIG. **1**, but see, e.g., FIG. **21** discussed below) electrically coupled to the camera system **22** for recording images obtained by the camera system **22** during use of the system **20**. The video recording device **32** may be attached to the frame **24** or it may be carried separately by the inspector (e.g., in a backpack or in a carrying case **34** as shown in FIG. **21**), for example. The video recording device **32** may record the images in a digital and/or analog format, for example. Thus, during use of the system **20** for locating a leak, an inspector may find a leak visually, as viewed on the display screen **30**, and then record detailed and focused images of the leak using the video recording device **32** for future observation and/or for obtaining a record of the leak.

The system **20** of the first embodiment has a battery **36** electrically coupled to the infrared camera system **22**. Preferably, the system **20** is powered by the battery **36** during use of the system **20** to allow the inspector to move about freely during an inspection. In other embodiments, however, the system **20** may be powered via a power cord by electricity from a wall outlet, from a generator, or from an alternator of a vehicle, for example. Typically, it will be less preferable to power the system **20** via a power cord, as it may limit the mobility of the inspector and/or slow down the inspection process.

FIG. **2** is a schematic of the infrared camera system **22** of FIG. **1** to illustrate some of the components therein. In the first embodiment, the passive infrared camera system **22** has one or more lenses **38** in a lens assembly **40** for optically focusing the image. Preferably, the lens assembly **40** is removable to allow for different lens assemblies (e.g., with different focal ranges) to be removably installed on the camera system **22**. The camera system **22** has a refrigerated portion **42** that comprises therein an infrared sensor device **44** and an optical bandpass filter **46**. The refrigerated portion **42** is preferably defined by an interior of a Dewar container **48**. Preferably, the Dewar container **48** has an evacuated region **50** surrounding the refrigerated portion **42** to provide insulation. The Dewar container **48** may be made from metal and it has at least one Dewar window **52** for allowing the infrared image from the lens assembly **40** to enter into the refrigerated portion **42**. The infrared sensor device **44**, located in the refrigerated portion **42**, is adapted to capture infrared images that come into the refrigerated portion **42** via the lens assembly **40**. In a preferred embodiment, the infrared sensor device **44** is a focal plane array (FPA) of Indium Antimonide (InSb) sensors (e.g., a 320×256 matrix) to provide a high sensitivity in the 3-5 micron range of infrared light, for example. Other materials may be used for the infrared sensor device **44** in other embodiments to provide high sensitivity to other wavelength ranges of infrared light. The infrared sensor device **44** is electrically coupled to other electronic components (represented generally by block **54** in FIG. **2**), which may be inside and/or outside of the camera system **22**. The design of the infrared sensor device **44** and the electronic components **54** for the camera system **22** may vary for other embodiments of the present invention.

The refrigerated portion **42** is cooled by a refrigeration system **60**. The refrigeration system **60** used may vary for

different embodiments of the present invention. Preferably, the refrigeration system **60** is capable of maintaining the temperature in the refrigerated portion **42** below about 100 K (i.e., less than about −173° C.). More preferably, the temperature in the refrigerated portion **42** is maintained between about 75 K and about 85 K by the refrigeration system **60**. In the first embodiment, the refrigeration system **60** includes a closed-cycle Stirling cryocooler, as illustrated schematically in FIG. **2**. The actual configuration of the Stirling cycle cryocooler **60** for a given embodiment may vary from that shown in FIG. **2**. A cold finger **62** may be used to provide a thermal communication between the refrigerated portion **42** and a regenerator cylinder **64**, as shown in FIG. **2**. The Stirling cycle cryocooler **60** may use helium as a refrigerant or cryogenic fluid, for example. In a preferred embodiment, a closed-cycle Stirling cryocooler **60** may be used to thermally stabilize the temperature in the refrigerated portion **42** at about 77 K, for example. A preferred infrared camera system **22**, for example, for use in an embodiment of the present invention is a Merlin™ mid-wavelength infrared (MWIR) high-performance camera available from Indigo Systems, Inc. in California.

As illustrated schematically in FIG. **2**, the optical bandpass filter **46** is located along an optical path between the lens assembly **40** and the infrared sensor device **44**, and hence infrared images are filtered by the optical bandpass filter **46** before reaching the infrared sensor device **44**. The optical bandpass filter **46** of the first embodiment has a pass band (bandpass transmittance range) located between about 3100 nm and about 3600 nm. Because the optical bandpass filter **46** is cooled, i.e., located in the refrigerated portion **42**, in the first embodiment, the filter **46** works better than if it were not cooled (e.g., not in the refrigerated portion **42**), and it allows for a more focused image than if a warm (uncooled) optical bandpass filter configuration were used. In a preferred embodiment, the optical bandpass filter **46** is cooled to a temperature below about 100 K. Cooling the optical bandpass filter **46** in the refrigerated portion **42** (i.e., “cold” filter configuration) provides a greater temperature contrast (greater temperature differential) between the leaking chemical and the optical bandpass filter **46**, which increases the sensitivity of the camera system **22** for imaging the leaking chemical. Cooling the optical bandpass filter **46** effectively reduces the background noise of the filter **46** (as perceived by the infrared sensor device **44**). When the optical bandpass filter **46** is not cooled (i.e., “warm” filter configuration), the level of background noise produced by the filter itself is much higher (relative to a cold filter configuration) and thus the sensitivity to detecting the infrared light absorbed by the leaking chemical after the infrared image passes through the warm filter is reduced. Also, in a warm filter configuration, the temperature difference between the optical bandpass filter and the leaking chemical is much smaller than that of a “cold” filter.

The camera system **22** of FIGS. **1** and **2**, of the first embodiment, is a passive infrared camera system. Hence, the camera system **22** relies on the background (whatever the background may be) to be a reflector of environmental light and heat to the camera system **22**. Most chemicals of interest have one or more absorbance bands (wavelength ranges where the absorbance of infrared light is orders of magnitude higher). For example, FIGS. **3A-3D** show absorbance graphs for methane ($CH4$) gas based on experimental data.

In each graph of FIGS. **3A-3D**, the vertical axis is absorbance (unitless) and the horizontal axis is wavelength (μm) of infrared light. Transmission and absorbance are inversely related. Transmission is typically defined as the fraction of light that reaches a detector after passing through a sample (e.g., an optical filter, a gas):

$$T=I/Io \text{ or } \%\ T=100(I/Io),$$

where I denotes light intensity reaching the detector after passing through a sample, Io denotes light intensity of a reference beam or source beam with no sample present, T denotes transmission (expressed as a fraction), and % T denotes transmission (expressed as a percentage). Absorbance is a logarithmic scale that increases as transmission decreases:

$$A=\log 10\ (Io/I),$$

where A denotes absorbance. Infrared radiation is often measured in units of wavelength (e.g., microns or nanometers). Also, infrared radiation is sometimes measured in units called wavenumbers (cm^{-1}):

$$\text{wavenumber } (cm^{-1})=107/\lambda=E/hc\times 1/100,$$

where λ is wavelength in nanometers, E is energy (J), h is Planck's constant (6.626×10^{-34} J·s), and c is the speed of light (3.0×10^{8} m/s). Hence, the wavenumber of a light wave is directly proportional to its wavelength and its energy.

FIG. **3**A shows the absorbance of methane from about 1.5 µm to about 16.5 µm (infrared light). Note that for methane, there are two major absorbance bands **71**, **72** where the absorbance of infrared light is much higher (orders of magnitude higher) than at other adjacent wavelengths. A first absorbance band **71** is located between about 3.1 µm and about 3.6 µm, and a second absorbance band **72** is located between about 7.2 µm and about 8.2 µm (see FIG. **3**A). FIG. **3**B shows a range of wavelengths between about 3.15 µm and about 3.45 µm to illustrate the first absorbance band **71** of FIG. **3**A in more detail. Note that the vertical scale for the graph in FIG. **3**A is the same as that of FIG. **3**B. FIG. **3**C shows a range of wavelengths between about 7.2 µm and about 8.2 µm to illustrate the second absorbance band **72** of FIG. **3**A in more detail. Note that the vertical scale of the graph in FIG. **3**C is orders of magnitude smaller than that of FIG. **3**A. There are also **1** other absorbance bands (**73**) for methane in the range shown in FIG. **3**A, but they have orders of magnitude less absorbance than the first and second absorbance bands **71**, **72**. For example, a third absorbance band **73** is shown in FIG. **3**A at about 2.3 µm. FIG. **3**D shows a range of wavelengths between about 2.15 µm and about 2.45 µm to illustrate the third absorbance band **73** in more detail. The vertical scale for the graph in FIG. **3**D is orders of magnitude smaller than that of FIGS. **3**A-**3**C. Hence, methane has a much higher absorbance of infrared light between about 3.1 µm and about 3.5 µm (overlapping or within the first absorption band **71**). Thus, an infrared camera system **22** adapted to detect infrared light between about 3-5 µm, for example, will have high sensitivity for imaging methane between about 3.1 µm and about 3.5 µm. The absorbance of methane at the second absorbance band **72** (see FIG. **3**A) may be easily detected as well by an infrared camera system **22** adapted to detect infrared light at that range (e.g., about 7-8 µm).

In a preferred embodiment of the present invention adapted to visually detect a certain chemical (and perhaps other chemicals as well) leaking from a component, the optical bandpass filter **46** is located in the refrigerated portion **42** of the infrared camera system **22** and the optical bandpass filter **46** has a pass band that is at least partially located in an absorption band for the chemical. For example, in the first embodiment, the optical bandpass filter **46** has a pass band **80** located between 3200 nm and 3550, as illustrated by the transmission curve for the filter **46** in FIG. **4**. The first embodiment is adapted to visually detect methane, for example, (as well as other chemicals). As discussed above, methane has a first absorption band **71** (see FIGS. **3**A and **3**B) located between about 3100 nm and about 3500 nm.

The optical bandpass filter **46** of the first embodiment has a full width at half maximum (HW) **82** of about 64.4 nm, a center wavelength **84** of about 3382 nm, and a peak transmission **86** of about 91.16%, as shown in transmission curve of FIG. **4**. The optical bandpass filter **46** of the first embodiment is a single bandpass passive filter formed on a quartz (SiO_2) substrate, which is currently preferred. A preferred bandpass filter providing such performance characteristics may be obtained from Spectrogon US, Inc. in New Jersey, for example. Other optical bandpass filters of other embodiments may have different transmission curves with different pass bands, different shapes, different materials, and different characteristics (e.g., full width at half maximum **82**, center wavelength **84**, peak transmission **86**, etc.). There are many different optical bandpass filters available from numerous manufacturers. Referring to FIG. **4**, the optical bandpass filter **46** of the first embodiment allows a transmittance greater than about 45% for infrared light between about 3360 nm and about 3400 nm to pass therethrough. Another optical bandpass filter (curve not shown) may be used in alternative, for example, that allows a transmittance greater than about 45% for infrared light between about 3350 nm and about 3390 nm to pass therethrough, which may provide similar or essentially the same results as the filter of the first embodiment.

FIG. **5** is a graph between 3000 nm and 3600 nm showing absorption bands for some common alkane chemicals: methane (**71**), ethane (**88**), propane (**90**), butane (**92**), and hexane (**94**), for example. In FIG. **5**, the pass band **80** for the filter **46** of the first embodiment has been overlaid with the absorption bands **71**, **88**, **90**, **92**, **94**. In FIG. **5**, note that at least part of the pass band **80** for the optical bandpass filter **46** is located within the first absorption band **71** for methane. The use of this optical bandpass filter **46** in the first embodiment provides a high sensitivity to infrared light being absorbed by methane between about 3200 nm and about 3500 nm (see FIG. **5**). Also, note that the pass band **80** for this optical bandpass filter **46** also provides a high sensitivity to infrared light being absorbed by ethane (**88**), propane (**90**), butane (**92**), and hexane (**94**) between about 3200 nm and about 3500 nm (see FIG. **5**). Although an embodiment may be adapted to detect a certain chemical leaking from a component, the same set up may also be useful and capable of detecting a set or group of chemicals, as is the case for the first embodiment of the present invention. Thus, the infrared camera system **22** of the first embodiment is adapted to provide a visible image representing an infrared image of methane, ethane, propane, butane, and/or hexane emanating from a component.

FIG. **6** is a graph between 3000 nm and 3600 nm showing absorption bands for some common alkene chemicals: propylene (**96**) and ethylene (**98**), for example. In FIG. **6** (as in FIG. **5**), the pass band **80** for the filter **46** of the first embodiment has been overlaid with the absorption bands of propylene (**96**) and ethylene (**98**) located between 3000 nm and 3600 nm. In FIG. **6**, note that at least part of the pass band **80** for the optical bandpass filter **46** is located within the absorption bands **96**, **98** shown for propylene and ethylene. Thus, the infrared camera system **22** of the first embodiment is also adapted to provide a visible image representing an infrared image of propylene and/or ethylene emanating from a component.

FIG. **7** is a graph between 3000 nm and 3600 nm showing absorption bands for some common aromatic chemicals:

o-xylene (**100**), toluene (**102**), and benzene (**104**), for example. In FIG. **7** (as in FIGS. **5** and **6**), the pass band **80** for the filter **46** of the first embodiment has been overlaid with the absorption bands of o-xylene (**100**), toluene (**102**), and benzene (**104**) located between 3000 nm and 3600 nm. In FIG. **7**, note that at least part of the pass band **80** for the optical bandpass filter **46** is located within the absorption bands **100**, **102**, **104** shown for o-xylene, toluene, and benzene. Thus, the infrared camera system **22** of the first embodiment is also adapted to provide a visible image representing an infrared image of o-xylene, toluene, and/or benzene emanating from a component.

In other embodiments adapted to visually detect a methane gas leak emanating from a component (and/or some other chemical having an absorption band overlapping or near that of the first absorption band **71** for methane), the optical bandpass filter **46** may have any of a variety of characteristics, including (but not limited to): the pass band of the optical bandpass filter having a center wavelength located between about 3375 nm and about 3385 nm; the optical bandpass filter being adapted to allow a transmittance greater than about 80% of infrared light between about 3365 nm and about 3395 nm to pass therethrough; the pass band of the optical bandpass filter having a center wavelength located between about 3340 nm and about 3440 nm; the pass band of the optical bandpass filter having a center wavelength between about 3360 nm and about 3380 nm; the pass band for the optical bandpass filter being located between about 3100 nm and about 3600 nm; the pass band for the optical bandpass filter being located between about 3200 nm and about 3500 nm; the pass band for the optical bandpass filter being located between about 3300 nm and about 3500 nm; the pass band of the optical bandpass filter having a full width at half maximum transmittance that is less than about 600 nm; the pass band of the optical bandpass filter having a full width at half maximum transmittance that is less than about 400 nm; the pass band of the optical bandpass filter having a full width at half maximum transmittance that is less than about 200 nm; the pass band of the optical bandpass filter having a full width at half maximum transmittance that is less than about 100 nm; the pass band of the optical bandpass filter having a full width at half maximum transmittance that is less than about 80 nm; the optical bandpass filter being adapted to allow a transmittance greater than about 70% at the center wavelength; the pass band for the optical bandpass filter having a center wavelength located within the absorbance band for the chemical; the pass band for the optical bandpass filter having a center wavelength located partially outside of the absorbance band for the chemical; and combinations thereof, for example.

In other embodiments, the optical bandpass filter **46** may comprise two or more optical filters (e.g., in series) located in the refrigerated portion **42** (i.e., cooled filters) to provide the same function as one single bandpass passive filter. For example, a first optical filter (not shown) of the optical bandpass filter **46** may have a high pass filter characteristic to allow infrared light greater than about 3100 nm to pass therethrough, and a second optical filter (not shown) of the optical bandpass filter **46** may have a low pass filter characteristic to allow infrared light less than about 3600 nm to pass therethrough, which together provide an effective pass band located between about 3100 nm and 3600 nm.

An embodiment of the present invention may be adapted to visually detect a leak of any of a wide variety of chemicals (or evaporated gases therefrom), including (but not limited to): hydrocarbon; methane; ethane; propane; butane; hexane; ethylene; propylene; acetylene; alcohol; ethanol; methanol; xylene; benzene; formaldehyde; 1,2 butadiene; 1,3 butadiene; butadiyne; acetone; gasoline; diesel fuel; petroleum; petrochemicals; petroleum by-product; volatile organic compound; volatile inorganic compound; crude oil products; crude oil by-products; and combinations thereof, for example. FIGS. **8-19** illustrate some example absorption bands (among many) for some example chemicals (among many) that may be detected while leaking from a component using an embodiment of the present invention, and some example pass bands (among many) for the optical bandpass filter **46** that may be used in an embodiment of the present invention.

In FIGS. **8-19**, the pass band **80** for the optical bandpass filter **46** is schematically represented by a rectangular box to show its approximate placement relative to the absorption bands of the chemicals. As is well known by those of ordinary skill in the art, the actual pass band for an optical bandpass filter will typically have some sort of curve shape (often a bell-curve shape) rather than being rectangular. The rectangular shape is merely used for schematic illustration, as the actual pass band (and the actual transmission curve) for an optical bandpass filter **46** of an embodiment may have any of a wide variety of shapes (symmetry, asymmetry, height, slope, skew, full width at half maximum, peak transmission, etc.).

FIG. **8** shows some absorption bands **71**, **88**, **90**, **92**, **94** for the same alkanes from FIG. **5** from 3000 nm to 3600 nm. In FIG. **8**, the pass band **80** for the optical bandpass filter **46** of a second embodiment is located between about 3300 nm and about 3400 nm with a full width at half maximum less than about 100 nm, for example. FIG. **9** shows some absorption bands **96**, **98** for the same alkenes from FIG. **6** from 3000 nm to 3600 nm. In FIG. **9**, the pass band **80** for the optical bandpass filter **46** of a third embodiment is located between about 3250 nm and about 3510 nm with a full width at half maximum less than about 250 nm, for example. FIG. **10** shows some absorption bands **100**, **102**, **104** for the same aromatics from FIG. **7** from 3000 nm to 3600 nm. In FIG. **10**, the pass band **80** for the optical bandpass filter **46** of a fourth embodiment is located between about 3200 nm and about 3580 nm with a full width at half maximum less than about 350 nm, for example.

FIG. **11** shows the first absorption band **71** for methane (see e.g., FIG. **3**A). In FIG. **11**, the pass band **80** for the optical bandpass filter **46** of a fifth embodiment is located between about 3200 nm and about 3350 nm with a full width at half maximum less than about 150 nm, for example. Hence, the fifth embodiment is adapted to visually detect methane leaks emanating from a component. FIG. **12** shows the second absorption band **72** for methane (see e.g., FIG. **3**A). In FIG. **12**, the pass band **80** for the optical bandpass filter **46** of a sixth embodiment is located between about 7600 nm and about 7800 nm with a full width at half maximum less than about 200 nm, for example. Thus, the sixth embodiment is also adapted to visually detect methane leaks emanating from a component.

FIG. **13** shows an absorption band **98** for ethylene located between about 3100 nm and about 3500 nm. In FIG. **13**, the pass band **80** for the optical bandpass filter **46** of a seventh embodiment is located between about 3200 nm and about 3500 nm with a full width at half maximum less than about 300 nm, for example. Hence, the seventh embodiment is adapted to visually detect ethylene leaks emanating from a component. FIG. **14** shows another absorption band **106** for ethylene, which is located between about 10000 nm and about 11500 nm. In FIG. **14**, the pass band **80** for the optical bandpass filter **46** of an eighth embodiment is located between about 10450 nm and about 10550 nm with a full width at half maximum less than about 100 nm, for example. Thus, the eighth embodiment is also adapted to visually detect ethylene leaks emanating from a component.

FIG. **15** shows an absorption band **96** for propylene located between about 3100 nm and about 3600 nm. In FIG. **15**, the pass band **80** for the optical bandpass filter **46** of a ninth embodiment is located between about 3200 nm and about 3600 nm with a full width at half maximum less than about 400 nm, for example. Hence, the ninth embodiment is adapted to visually detect propylene leaks emanating from a component. FIG. **16** shows another absorption band **108** for propylene, which is located between about 10000 nm and about 11500 nm. In FIG. **16**, the pass band **80** for the optical bandpass filter **46** of a tenth embodiment is located between about 10900 nm and about 11000 nm with a full width at half maximum less than about 100 nm, for example. Thus, the tenth embodiment is also adapted to visually detect propylene leaks emanating from a component.

FIG. **17** shows an absorption band **17** for 1,3 butadiene located between about 3100 nm and about 3500 nm. In FIG. **17**, the pass band **80** for the optical bandpass filter **46** of an eleventh embodiment is located between about 3150 nm and about 3300 nm with a full width at half maximum less than about 150 nm, for example. Hence, the eleventh embodiment is adapted to visually detect 1,3 butadiene leaks emanating from a component. Note that in another embodiment (not shown), the pass band of the eleventh embodiment may be located between about 3200 nm and about 3400 nm, for example, as another variation. If it is of particular interest to detect leaks of a certain chemical (or set of chemicals), it is preferred to have the pass band **80** overlaying the absorption band where the area under the absorption band is higher to provide better detection sensitivity. The width of the pass band **80** may or may not be critical for a given chemical, depending largely upon the characteristic shape of that chemical's absorption band (e.g., width along wavelength axis, height along absorption axis).

FIG. **18** shows another absorption band **112** for 1,3 butadiene, which is located between about 9000 nm and about 12000 nm. In FIG. **16**, the pass band **80** for the optical bandpass filter **46** of a twelfth embodiment is located between about 9000 nm and about 12000 nm with a full width at half maximum less than about 150 nm, for example. Thus, the twelfth embodiment is also adapted to visually detect 1,3 butadiene leaks emanating from a component. Note that the pass band **80** in FIG. **18** is not centered on the largest peak **114** of the absorption band **112**. In another embodiment (not shown), it may be preferred to have the pass band **80** centered at or closer to the largest peak **114** of the absorption band **112**.

FIG. **19** shows an absorption band **116** for sulfur hexafluoride (SF_6) located between about 10000 nm and about 11500 nm. In FIG. **19**, the pass band **80** for the optical bandpass filter **46** of a thirteenth embodiment is located between about 10500 nm and about 10600 nm with a full width at half maximum less than about 100 nm, for example. Thus, the thirteenth embodiment is adapted to visually detect SF_6 leaks emanating from a component. Sulfur hexafluoride is often used in switching gear for electrical equipment and its emissions are harmful to the environment. Hence, an embodiment of the present invention may be used to visually detect SF_6 leaks emanating from electrical equipment, for example.

FIG. **20** shows a fourteenth embodiment of the present invention. In the fourteenth embodiment, the refrigeration system **60** of the infrared camera system **22** has a chamber **126** adapted to retain liquid nitrogen therein. The liquid nitrogen has thermal communication with the refrigerated portion **42** to cool the infrared sensor device **44** and optical bandpass filter **46** located therein. For the fourteenth embodiment, a currently preferred infrared camera system (**22**) is the InSb Laboratory Camera by Indigo System, Inc. of California, particularly when made portable (as shown in FIG. **20**). The frame **24**, battery **36**, and display screen **30** may be the same on the fourteenth embodiment (FIG. **20**) as that of the first embodiment (FIG. **1**). To provide for better viewing of the display screen **30** in a bright environment, a shroud, hood, or visor may be provided around the display screen **30**. For example, the fourteenth embodiment shown in FIG. **20** has a light shield **128** located proximate to the screen **30** for partially shielding the screen **30** from ambient light. During use, an inspector may place his face up to or against the edge of the shroud to shield the environmental light from the display screen **30** and allow the inspector to view the screen with the darkened enclosure formed.

An embodiment of the present invention may be used to inspect any of a wide variety of components having the chemical (or chemicals) of interest therein, including (but not limited to): a pipe, a compressor, an engine, a valve, a container, a tank, a switch, a reservoir, a fitting, a connector, a hose, a flare, an exhaust outlet, a machine, a vent for a blow-off valve, and combinations thereof, for example. Some example uses of embodiments of the present invention will be described next.

An embodiment of the present invention may be used to visually detect the evaporation (i.e., fumes) of petroleum products leaking from a component, such as a valve or pipe fitting. An advantage of an embodiment of the present invention over prior methods of detecting leaks (e.g., flame pack ionizer, sniffer device) is that the inspector can actually see the leak flowing by the visible image (representing the infrared image) provided by the infrared camera system **22**. Using a sniffer device, the sensor has to be within the flow stream to detect it, which requires close proximity and thorough scanning to cover an entire component or area. Using an embodiment of the present invention, an inspector can visually scan a large area in a much shorter period of time, and the inspector can do so from a distance. Thus, the inspector may not need to climb on and around equipment, which may be dangerous to the inspector. Also, pipes needing inspection are often located overhead along a roof, which is difficult to inspect with a sniffer device. But with an embodiment of the present invention, an inspector may stand below the pipes and perform the visual inspection using the infrared camera system **22** from the ground (from a distance).

Also, an inspector may combine the use of an embodiment of the present invention with other inspection methods. For example, after an inspector locates a leak visually with the infrared camera system **22** of an embodiment, the inspector could then do a further analysis of the leak using other measurement tools.

In a first method of using an embodiment of the present invention, an embodiment of the present invention (e.g., first embodiment) is used to visually inspect a natural gas (methane) regulator station **120**. Usually, such regulator stations are enclosed within the boundary of a fence **122**. As shown in FIG. **21**, an inspector **124** using an embodiment of the present invention may inspect the regulator station **120** from a location outside of the boundary defined by the fence **122**, even though the regulator station **120** is located within the boundary defined by the fence **122**. If the fence **122** cannot be seen through, as with a chain-link fence or a steel tubing fence, the inspector **124** may be able to visually inspect the regulator station **120** over the fence **122**. For example, the inspector **124** could stand on an object (e.g., truck bed). As another alternative, an inspector **124** could be lifted by a boom on a boom-truck, for example. Also, the inspector **124** may perform the inspection within the fence boundary **122**.

For most methods of using an embodiment of the present invention to visually detect a leak of a chemical (or chemicals) emanating from a component, the following steps will be performed. An inspector aims the infrared camera system **22** toward the component or components of interest. Infrared images of the component and background enter the camera system **22** via the lens assembly **40** (at least one lens **38**) (see e.g., camera system **22** in FIG. **2**). The infrared image passes through the optical bandpass filter **46** on its way to the infrared sensor device **44**. The infrared image is filtered by the optical bandpass filter **46** in accordance with the characteristics of the filter **46** (i.e., its pass band **80**). The filtered infrared image is then received by the infrared sensor device **44**, which converts the filtered infrared image to an electrical signal representing the filtered infrared image. This electrical signal is then electronically processed, within the camera system **22** (see e.g., FIG. **2**) and/or externally by another device outside of the camera system **22**, to provide a visible image representing the filtered infrared image. This visible image may be viewed in real time by the inspector, viewed by another person at another location (e.g., remotely located), recorded, transmitted to another device, transmitted to another location, or combinations thereof, for example.

In a method of the present invention, an inspector may obtain images and evaluate the images while performing the inspection. In another method, the inspector may do the same, and in addition, the images may be recorded and reviewed a second time. The second review may be performed by the same inspector, another person, or by a computer using image recognition software. The second review may find anything missed in the original survey. The ability to have a second review is not available with many conventional ways of doing leak surveys (e.g., using flame-packs) because a focused visual image of the inspection is not provided. Thus, a better leak survey requiring the same time and money (or less) may be performed using a method of the present invention, plus a visual record of the leak may be stored and may be viewed numerous times.

An advantage of an embodiment of the present invention is that it may allow the recording of the images obtained during the visual inspection. Such recordings may be useful in a number of ways. The recorded image obtained in the field may be transmitted (e.g., in real time or later) to a reviewer (person or computer system) at another location or a remote location. Sometimes in the field where bright conditions exist outside, for example, it may be difficult for the inspector to see small details on the video monitor or display screen. Also, the inspection conditions may not be conducive to a careful study of the image during the inspection. Thus, a reviewer located in a dark and stable environment may provide a better review of the images obtained by the system. The images may be recorded by a device attached to the infrared camera system, recorded at a remote location after being transmitted, or recorded by a separate device not attached to the infrared camera system **22**, for example. An image may be transmitted from the camera system **22** to another device (which may or may not be remotely located) by any of a wide variety of communication means, including (but not limited to): a cable, a wire, between wireless communication devices, via a network connection, via the Internet, or combinations thereof, for example. The images provided by the infrared camera system may be recorded continuously during an inspection and/or they may be recorded as desired over any period of time.

Referring to FIG. **21**, note that a video recording device is located in a carrying case separate from the infrared camera system. In other embodiments of the present invention, other components of the system may be separate from the infrared camera system (e.g., carried in a backpack). This may be preferred so that the camera system may be lighter and held easier. An embodiment is contemplated where most of the system components are located in a back pack or some other carrying case (e.g., case with wheels and handle) so that the camera portion having the lens, optical bandpass filter, and infrared sensors may be located in a smaller hand held unit. Such a hand held unit may include a small flat panel display screen, for example. It is also contemplated that the visible images from the camera may be displayed to an inspector using a system that projects the images directly into one or more of the inspector's eyes or onto an interior surface of a eyepiece or eyeglasses. One of ordinary skill in the art will realize many different types and sizes of display screens or projectors that may be incorporated into or used for an embodiment of the present invention.

It is also contemplated that an embodiment of the present invention may be made intrinsically safe to allow for greater flexibility and usages of the system for performing inspections. Also, providing an embodiment that incorporates an intrinsically safe infrared camera system may provide the advantage of entering plants for performing inspections without the need for a hot work permit to be issued and/or without the need for other safety precautions normally associated with the use of a non-intrinsically safe inspection system.

It is further contemplated that an embodiment of the present invention may incorporate a halogen light (e.g., attached to the camera system or separately provided) to provide a greater thermal contrast for the camera system using the heat radiated by the halogen light to change the temperature of the background slightly. It may be useful to use the halogen light on an as needed basis to get a more detailed image (higher sensitivity or better image resolution) of a leak after it is located (such as for making a recording of the leak).

The visual identification of a leak may be performed at another location remote from the infrared camera system and/or remote from the leak location, e.g., while viewing a recording of the images, while viewing an image transmitted to the remote location, or combinations thereof, for example. As an example, an inspection team flying over a transmission line in a helicopter (discussed further below) may be concentrating on obtaining a good image of the transmission line and precisely following GPS coordinates of the transmission line. While in a helicopter, it may be difficult for the inspection team to concentrate on reviewing the images obtained during the inspection process. The visual images obtained by the infrared camera system may be recorded for and/or transmitted to a reviewer. The reviewer may then carefully review the images to look for leaks. Such review may be performed in real-time, which would allow the reviewer to communicate with and instruct the inspectors to go back to a suspect location for a confirmation (i.e., hovering over a certain location and obtaining more images of a single location). Or if the visual inspections are recorded, a reviewer may study the inspection images at a later time. Hence, one of the members of the inspection team may later sit down in an environment more conducive to studying the images to provide the review of the images. Then, if needed or desired, a closer or more lengthy inspection of suspect locations may be performed later.

Government safety regulations and rules typically require that gas or petroleum product transmission lines and distribution lines be inspected at certain regular intervals. If a company does not comply with such rules and regulations, the company may be charged steep fines. Also, if there is some type of accident or incident where a leaking or ruptured line causes an explosion or fire, the company will want to provide evidence that they were diligent and not negligent in performing an inspection of that line. Hence, another benefit of being able to record a focused image of the visual inspection is the ability to have a record of the inspection. In an embodiment of the present invention, GPS coordinates, a date stamp, and/or a time stamp may be recorded onto or embedded within the recorded images of the visual inspection. This will provide evidence that an inspection was performed for a particular location at a particular date and time. Such records may be stored (in analog or digital format) on some type of storage medium (e.g., video tape, CD, DVD, database, hard drive, etc.) for future reference.

In a preferred embodiment and/or method of the present invention, inspection information may be displayed and or recorded along with the recording/displaying of the visible image representing the filtered infrared image. The inspection information may include any relevant information desired, including (but not limited to): inspection location name, inspection location address, component name, component identification information, global positioning coordinates, a date, a time of day, an inspector's name, an inspection company's name, one or more camera system setting values, or combinations thereof, for example. Also, voice notes may be recorded onto or along with the images on a medium (e.g., voice notes recorded on a video of inspection). Such inspection information may be embedded within the visible image or may be recorded and tracked separately (e.g., in a separate file, as a header file, etc.).

In a second method of the present invention, an embodiment of the present invention may be used to inspect numerous fenced yards **130** from a single location, from outside the yards **130**, and/or from a single yard **130**. FIG. **22** shows a housing configuration found in many neighborhoods, where there is no alley behind the houses **132**. Instead, only a fence **134** may separate two or more adjacent backyards **130**. In FIG. **22**, an underground natural gas distribution line **136** is shown in dashed lines, which run across numerous backyards **130**. Using conventional leak survey techniques, an inspector would need to enter each backyard **130** to inspect the line in all six of the yards **130** shown in FIG. **22**. However, because a leak may be detected visually using an embodiment of the present invention, an inspector may enter only one backyard **130** and see into each of the adjacent yards **130** (as indicated by the arrows in FIG. **22**). Thus, only one customer needs to be disturbed for the inspection, rather than six. Also, an inspector may attach the infrared camera system **22** to a boom on a truck, or he may be standing in the boom holding the camera system **22**, located at an end of a street or in an alley to obtain visual access to numerous backyards **130**. Thus, using an embodiment of the present invention, multiple backyards may be surveyed for line leaks visually using an infrared camera system **22** from a single location (e.g., from a single backyard **130** looking over the fences **134**, or from a boom).

Many residential meters for natural gas are located next to a house (e.g., between houses), remote from where a vehicle may drive. Such distribution lines must be periodically tested for leaks. In such cases, using a conventional method of leak surveying, the inspector typically walks to each meter to perform the leak survey. In a third method of the present invention, such meters and distribution lines may be surveyed visually using an infrared camera system from a vehicle. For example, an inspector may aim an infrared camera system at the distribution lines while driving past each home without leaving the street or the vehicle. This can save a great deal of time and money for saved man hours. This same technique of using an embodiment of the present invention may be used for inspecting components located adjacent to or on any building, not just residential houses.

In a fourth method of performing an inspection with an embodiment of the present invention, the inspection may be performed in stages. A first stage may be that the inspector views the area of inspection using the infrared camera system from a distance to make sure there is not a huge leak that the inspector is about to walk or drive into. This would be mainly for the safety of the inspector. Many chemicals have little or no odor and are invisible to the human eye. Hence, an inspector could be driving or walking right into a very dangerous situation. Next, after the inspector confirms that there is not a huge leak (e.g., large flow of chemical emanating from the site), the inspector can perform a more detailed inspection looking for medium, small, and/or very small leaks.

Sometimes gas or chemical leaks or chemical spills in cities or near highways are reported to the police first, and the police send out officers to direct traffic away from the gas/chemical leak for the safety of the public. However, there have been instances where an officer drives right into the stream of the leak without knowing it and ignites an explosion, which may injure or kill the officer. The same dangers exist for repair persons entering such a location. Thus, it would be beneficial to incorporate a method of using an embodiment of the present invention into a first response system. For example, if a chemical leak/spill is suspected, a helicopter with an infrared camera system of an embodiment may be flown toward the suspected location to assess it visually from a safe distance using a method of the present invention. By doing so, the magnitude and direction of the fumes from a leak or spill may be determined and reported quickly and safely. It is often difficult to initially determine the magnitude of the leak or spill using conventional methods. As another example, an embodiment of the present invention could be used by firemen from their fire truck as they approach a scene of a reported leak or spill. Likewise, a maintenance or safety crew at a processing plant equipped with an embodiment of the present invention could assess a situation from a safe distance as they enter to investigate a suspected leak or spill.

The aiming of the infrared camera system of an embodiment towards a component being inspected may be performed from a vehicle. Part or all of the system may be attached to the vehicle or supported by the vehicle, and/or may be held be a person in the vehicle, for example. It may be any type or kind of vehicle suitable for the inspection, including (but not limited to): a truck, a car, a motorcycle, a bicycle, a boat, a ship, a personal watercraft, a fixed-wing airplane, a rotary wing vehicle (e.g., helicopter, gyro-plane), a powered paraglider, an ultralight aircraft, a powered glider, a glider, a balloon, a blimp, a remote controlled vehicle, an unmanned aerial vehicle, and combinations thereof. The vehicle may be moving or stopped during part or all of the inspection. If the infrared camera system is mounted on or attached to a vehicle, it may be desirable to have the camera system mounted on some type of stabilizing platform or stand, as is commonly used in the movie filming industry (e.g., gyro-stabilized apparatus). Such a stabilizing platform may provide the ability to obtain better images of a test site from a moving vehicle (e.g., truck, ATV, helicopter, blimp, airplane).

An embodiment may be attached to a satellite to provide inspections from space. One of the advantages of infrared is that it can see through most clouds. The range of inspection is limited only by a line of sight for a method of inspecting using an embodiment of the present invention. Hence, as long as the chemical leak or the trail of fumes emitted from the leak are within a line of sight (e.g., not blocked by trees, heavy rain, buildings, or structures), an infrared image may be obtained. The size/type/configuration of lens can thus be increased/decreased/varied as needed to provide focus for a given range.

The typical method of finding leaks on cross country transmission lines is to walk along the lines using a sniffer device (flame-pack detector), or in some cases where there are no fences one may drive a truck or ATV with mounted sniffers, up and down the lines. One of the disadvantages of this method is that if the wind is blowing away from the sniffer or if the vehicle or the walker is upwind from the leak, the sniffer probably will not detect a leak; thus missing the leak altogether. The next problem is that a lot of the gathering lines have now been overgrown with houses, buildings, and backyard fences. This makes it very impractical to check for leaks in and around residential back yards using conventional techniques. Companies often perform aerial surveys to look for encroachments or blocking of their easement. Such surveys may be performed simultaneous with a visual infrared inspection for leaks.

Also, truck mounted sniffers are actually built for leak detection in the cities not for cross country transmission lines. The difference being that the size of leak in cities versus transmission lines can be great. There is a danger of a pickup with a hot catalytic converter with grass stuck to it being driven onto a 200 mcf per day leak. Such a scenario can result in an explosion that can kill the driver and destroy the equipment. The conventional leak survey equipment requires the inspector to be in close proximity within the stream of gas flow to detect it. By the time the gas is detected for a large leak, it may be too late. Using an embodiment of the present invention, a large leak may be seen from more than ½ mile away, and other leaks may be seen from a distance.

An embodiment of the present invention may be attached to a helicopter or plane, for example, and flown over a transmission line at a relatively high rate of speed (e.g., 60-120 mph) while visual images are recorded using the infrared camera system. Even though the speed may be too great for an inspector to spot a leak on-the-fly, a computer image recognition system may be able to detect the leak at the higher speed, or a second review playing back the recording at a slower speed may be able to catch missed leaks.

Often the leaks in transmission lines are found by locating dead vegetation where the gas is leaking through the ground. However, during the winter when the grass is brown, this method may not work. Also in some areas, such as desert areas, there may be no vegetation where the leak exists. Thus, using a method of the present invention, leaks from a buried transmission line may be easily detected visually from a short or long distance away with an embodiment of the present invention.

Down in the swamp land of southern Louisiana, for example, it is almost impossible to walk the lines. Instead, the operators typically fly over their lines and look for discolored vegetation. However, a colony of ants can also leave an area of discolored vegetation that looks like a gas leak from the air. With an embodiment of the present invention mounted on a helicopter, for example, one may hover over an area suspected of having a leak, and record a short sequence of the specific area using the infrared camera system **22** to easily determine if there is a leak. In alternative, the entire line may be visually scanned using an infrared camera system **22** to look for leaks.

Most transmission lines have pressure gauges and automated valves at certain intervals (check points) along the line. Often an operator has the equipment to see a pressure drop across the line between points which may be 50-100 miles apart, for example. Along such a long distance between the two points, there may be several leaks. Typically, it is difficult to determine which of the leaks is larger. Thus, many smaller leaks may be fixed before finding the larger leak. Using an embodiment of the present invention, the larger leaks may be distinguished from the smaller leaks. Thus, the larger leaks may be located and repaired first, as they are usually the first priority.

Sometimes when one leak is being repaired, it can cause a new leak in the same pipe at another location due to movement of the pipe during the repair operation. In a method of the present invention, the nearby portions of the repaired line may be quickly and easily inspected visually using an embodiment of the present invention to determine whether another leak exists along that line.

When cast iron or old metal lines develop leaks, the pipe material often becomes saturated with the leaking gas. Also, the dirt around and above a gas leak (for any type of pipe) often becomes saturated with gas. Thus, after performing a repair and replacing the dirt, a sniffer detector may falsely indicate that the leak is still present because it may be detecting the remaining gas saturated in the dirt and/or pipe. Also, if the gas is odorized, the smell will often linger for several days as it slowly dissipates from the dirt, which can lead to follow-up complaints by persons still smelling the gas. However, performing a visual gas leak inspection with an embodiment of the present invention, may quickly determine whether the leak still exists after the repairs (before or after replacing the dirt). In most cases, the visual test will be able to distinguish remaining petroleum products saturated in the dirt and an actual leak (showing a stream of blowing gas, for example). This can save companies a lot of money on service calls and ensure that the leaks are actually fixed more accurately and more reliably.

Leak surveys in downtown business districts often have to be conducted at night due to traffic. With proper flight clearance, an infrared camera system **22** may be mounted on a helicopter, for example, to perform these leak surveys from a helicopter during the daytime and save overtime hours for crews. One of the advantages of performing a leak survey from above using an infrared camera system **22** to visually detect leaks is that the ground often retains heat to provide a good thermal contrast and thus a better background contrast for viewing the leak with infrared, as compared to the sky or a structure in many cases.

Another method of using an embodiment of the present invention is the detection of leaks in large tanker vessels transporting petroleum products by sea. Using an infrared camera system of an embodiment of the present invention, leaks to the environment may be detected visually from a safe distance (e.g., on land, on a dock) by the shipping company or by enforcement/regulatory agencies (e.g., EPA, DOT). Such ships carrying chemicals or petroleum products may be visually inspected as they pass by or as they approach, for example.

Inspections may also be performed onboard the boat, ship, or vessel. Also, enclosed areas within a ship may be periodically or continuously monitored using a portable or permanently-installed/stationary infrared camera system of an embodiment, for example.

Another method of using an embodiment of the present invention is detecting gas leaks on petroleum production rigs. Often such rigs are approached via helicopter. An infrared camera system **22** adapted to visually image a petroleum product leak may be mounted on a crew helicopter. This would enable the crew on the helicopter to scan for gas leaks on gas platforms out in the ocean as they approach and before they land, for example. This would reduce or eliminate the risk of landing a helicopter with a hot engine into a gas leak. Furthermore, in another embodiment, a permanently-mounted/stationary infrared camera system **22** may be mounted at certain locations around the rig to provide a continuous or periodic visual leak survey.

In another method of using an embodiment of the present invention, detection of chemical leaks may be performed at factories, processing plants, manufacturing facilities, refineries, and/or petroleum separation plants. At some plants, they typically do monthly valve maintenance and inspections, for example. The problem with the way that they are currently done is that the flame-pack detector will often trigger on grease or WD-40 that is used on the valves for lubrication, for example. However, an infrared camera system **22** may be tuned (e.g., using an optical bandpass filter **46** having a certain pass band **80**) so that it does not have the ability to see or detect these greases and lubricants. Hence, such an embodiment may distinguish between the lubricants and gas leaks. If the fumes of the greases and/or lubricants are imaged by the camera system **22**, the visual observation of the fumes and the pattern of the fumes may allow the inspector to discern that it is not a leak and it is merely a lubricant evaporating. Often valves have been repacked due to a false leak detection triggered by lubricants on the valves, which is very costly and a waste of resources.

Another method of the present invention is the detection of leaks in the petrochemical industry or other chemical producing industries, using an embodiment of the present invention to visually detect leaks. Detection of such leaks may be performed at any stage from the exploration to the processing and production to the transporting of the chemicals produced to the containers storing the chemicals to the equipment using the chemicals, for example. A pipe or transportation line carrying the chemical may be visually inspected for leaks using an embodiment of the present invention. As another example, various pipes, connections, and equipment at a processing plant may be visually inspected or monitored for leaks using an embodiment of the present invention. Storage containers, cargo vessels, or truck trailers used for storing and/or transporting the chemicals may be visually inspected for leaks using an embodiment of the present invention, for example. Some example chemicals include (but are not limited to): ethylene, propylene, acetylene, propane, alcohol, ethanol, methanol, xylene, benzene, butadiene, acetone, compounds thereof, and combinations thereof.

An embodiment of the present invention may be used to perform a leak survey in and/or around a plant. An advantage of the present invention is that large leaks can be distinguished from small leaks, visually. Often the small leaks go unrepaired because they cannot be found easily using conventional methods. Even small leaks can be very dangerous in an enclosed area where flammable gases become trapped therein. Also, in many processing plants, the gases may have no odor added to them, which means a person would not smell the gases. Even where the gases are odorized, it is often difficult or impractical to detect all of the leaks. In most processing plants, the plant smells like chemicals everywhere because there are lots of small leaks. If the plant personnel could quickly and easily find the leaks, as they can using an embodiment of the present invention, it may become economical to fix even the smallest leaks. If that becomes the case, then processing plants may cease to smell like chemicals all the time. On one test of an embodiment of the present invention, 15 leaks were found in one region of a large plant in just 30 minutes, which is faster than most conventional methods of inspection. Another advantage of using an embodiment of the present invention is that the inspector often does not have to crawl on and around the equipment and pipes to find the leaks, as they may be seen with the infrared camera system when a line of sight is provided. Using a sniffer detector, however, an inspector would be required to get his detector within the flow of the gas leak to detect it.

Enclosed areas within a plant or any area at a plant may be periodically or continuously monitored using a portable or permanently-installed/stationary infrared camera system of an embodiment, for example. A permanently-mounted infrared camera of an embodiment may use a closed-cycle Stirling cryocooler, for example, and may be similar to the first embodiment of FIG. **1** but adapted to be mounted in a building. An entire network of permanently mounted cameras may be strategically located throughout a plant to provide partial or complete coverage of the plant. In one embodiment, a person may monitor the images provided by the cameras continuously or periodically. In another embodiment, a computer system with image recognition software may be used to detect changes in the image or motion in an image indicating a stream of gas or liquid flow at a leak.

Also, many plants or factories have blow-off valves that vent out of the roof. A single plant may have numerous vents with vent exits being more than 30 feet high. However, using an infrared camera system in accordance with the present invention, gases exiting such vents may be quickly surveyed from a distance on the ground, for example. Also, flare emissions burning on the top of a tower structure may be visually inspected using an embodiment of the present invention from a distance (e.g., more than 10 feet away, from the ground, etc.).

Recorded inspection data from prior inspections may be useful for a plant manager. If an inspection is performed in a plant and the same leak is found again in a subsequent survey, as documented visually with video by inspectors, the plant manager can then know that either the leak was never repaired or it is a re-occurring leak.

In yet another method of using an embodiment of the present invention, government regulatory agencies (e.g., railroad commission, DOT, EPA) may themselves perform visual inspections easily and quickly using an infrared camera system to determine if a plant or factory is emitting petroleum products or other chemicals that should not be emitted into the environment (e.g., volatile organic compounds, volatile inorganic compounds, nitrous oxide, unburned chemicals, etc.). Such inspections by government regulatory agencies may be performed randomly as surprise inspections to enforce stricter compliance with environmental rules and regulations. Also, government regulatory agencies may require recordings of inspections to be retained so that they can review them. Furthermore, a government regulatory agency may then perform follow-up inspections visually at targeted areas where a leak was known from a prior inspection to ensure that the leaks were repaired in a timely manner. A government regulatory agency may also review a series of test videos to look for unrepaired leak scenarios. Thus, there are numerous methods of using an embodiment of the present invention that may be useful to a government regulatory agency.

In another method of the present invention, fuel leaks (or other chemical or fluid leaks) on a vehicle may be easily found using an embodiment of the present invention. For example, on a Lotus Esprit car, the gas tanks are notorious for rusting and developing small pinhole leaks which are difficult to locate and find. It is not cost efficient to remove the gas tanks for inspection, as the engine must be removed to get the gas tanks out of the vehicle. Also, such cars are notorious for having leaks at high pressure and/or low pressure fuel lines, which can cause engine fires. Furthermore, the toxic fumes from an engine bay where a fuel leak exists often make there way into the cabin, which is dangerous and obnoxious for the cabin occupants. An embodiment of the present invention may be used to accurately pinpoint and find such leaks. Also, such a method may be applied to locate fuel leaks in other vehicles, such as airplanes, boats, helicopter, and personal watercraft, for example. An infrared camera system **22** of the present invention may be used to locate refrigerant leaks quickly on a vehicle. Also, an embodiment of the present invention may be used to locate gas or refrigerant leaks in home or building HVAC equipment.

FIGS. **23A-31B** are some images generated by an embodiment of the present invention during experimental testing. Specifically, FIGS. **23A-31B** were generated using the fourteenth embodiment (see FIG. **20**) having an optical bandpass filter **46** with a pass band **80** about the same as that shown in FIG. **4**.

FIGS. **23A-23D** are visible images representing filtered infrared images of a gas **140** leaking from the ground (e.g., a buried line). The images of FIGS. **23A-23D** are from a sequence of images extracted from a video recording of this leak **140**. Although sometimes difficult to illustrate in still images, the movement of the leak stream **140** in a video (sequence of images) makes the leak **140** much more apparent. Very small leaks (low flowrate) that do not show up in one still image are often easily seen in a video because the movement of the leak stream or fumes can be seen in a video.

FIGS. **24A-24D** are images obtained by an embodiment of the present invention showing a gas **140** leaking from a compressor at a flange **142** on the discharge side. The sequence of images in FIGS. **24A-24D** were extracted from a video showing the gas **140** streaming from the flange **142**.

FIGS. **25A-25D** are images obtained by an embodiment of the present invention showing a natural gas (methane) leak **140** resulting from a crew cutting 1½ inch gas line with approximately 12 psi pressure. It is an underground gas line (not shown). Although the large cloud of methane **140** exiting the hole in the ground is somewhat dispersed and difficult to see in the still images of FIGS. **25A-25D**, it is easily seen in the video due to the movement of the cloud **140**. Note also that the images of background objects are easy to discern and focused in the original video, which aids in providing a context of where the leak **140** is coming from.

FIG. **26** is an image obtained by an embodiment of the present invention and extracted from a recorded video sequence. FIG. **26** shows a large gas leak **140** emanating from a component **144** in a processing plant.

FIG. **27** is also an image obtained by an embodiment of the present invention and extracted from a recorded video sequence. FIG. **27** shows a gas **140** flowing from a vent tube **146** extending from a building roof **148** (about 30 feet high). This image was obtained by a person at ground level. The gas flowing out of the vent **146** may be from a blow-off valve that is exhausting to the environment, which may be indicative of a condition at that component causing the blow-valve to be opened.

FIGS. **28A** and **28B** are more images obtained by an embodiment of the present invention and extracted from a recorded video sequence. FIGS. **28A** and **28B** show a man pumping gasoline into his truck at a gas pump. Note in FIG. **28B** that as the gas is pumping into the gas tank, the gas fumes **140** can be seen just above the pump handle with the truck bed as the background.

FIG. **29** shows an image of propane **140** exiting a propane bottle in a test of the system for detecting propane. FIG. **30** shows an image of a small gas leak **140** emanating from a component at a processing plant. The leak appears as a faint black cloud **140** in the image. This is a relative small leak.

FIGS. **31A** and **31B** are images taken from a helicopter flying over a test site. In this test, a propane bottle was opened, as in FIG. **29**, in a field. In FIG. **31A**, the propane stream **140** can be seen with the infrared camera system at ½ mile away while the helicopter is moving toward the test site at about 60 knots. FIG. **31B** is a more focused image of the propane stream **140** at a closer distance than that of FIG. **31A**. Note that a person **150** can be seen standing next to the propane stream **140** and next to a bush **152** in FIG. **31B**. Also, note that two roads can be seen in FIGS. **31A** and **31B**, which provide reference points and context of the location of the propane stream **140**.

An advantage of an embodiment of the present invention, as illustrated in these images of FIGS. **23A-31B**, is that often the background and surrounding objects can be clearly seen in the image along with the leak or stream of gas **140**. This can be very useful in providing a reference or context of where the leak is located and aids in documenting the leak using video images.

In a recent test of an embodiment of the present invention before the US EPA, in comparison with other infrared camera systems, the embodiment of the present invention greatly outperformed the other systems. After this test before the US EPA, new US EPA regulations are expected to be released by the end of 2004, or shortly thereafter, allowing for the use of infrared camera systems to perform visual leak surveys. This demonstrates a long felt need in the industry that others have failed to meet, and that an embodiment of the present invention is now able to fulfill.

Also, after the US EPA test described above, there has been an explosive demand for embodiments of the present invention and for services using an embodiment of the present invention. This demonstrates the commercial success and great demand for embodiments of the present invention and for services using embodiments of the present invention.

FIG. **32** illustrates a schematic of a first dual camera embodiment of the present invention. This system includes a first video camera **22**, which is an infrared camera system with an optical bandpass filter **46** (preferably installed in a refrigerated portion **42** thereof, i.e., cold filter configuration); a second video camera **154** (e.g., another infrared camera system); an image splitter **156**; a lens assembly **158**; and an image processor/recorder **160**. The second video camera **154** may be any infrared camera system that can obtain an image from the same type of lens as the first video camera **22**. The second video camera **154** may be an infrared camera with filters so that it will not image the leaking chemical. The first video camera **22** is an infrared camera adapted to provide a focused visual image of a chemical leak by using an optical bandpass filter **46** for a specific pass band **80** (e.g., pass band **80** with a wavelength range centered at about 3.38 microns). For example, the first video camera **22** may be any of the embodiments discussed above (see e.g., FIGS. **1-20**). The first video camera **22** may receive the same image as the second video camera **154** from the same lens **158** via the image splitter **156**. The video signal from each camera may be output to the image processor/recorder **160**. The image processor/recorder **160** may simply record the two video feeds for later processing. In an alternative, the image processor/

recorder **160** may be a system (e.g., a computer system running software for processing the video data) or specialized/dedicated hardware for processing the two video feeds. Preferably, the images from the second video camera **154** are compared to the images from the first video camera **22** by a software program running on a computer system. Because a gas leak, for example, will not appear in the image from the second video camera **154**, the presence of the gas plume shown in the infrared image from the first camera **22** may be detected as a difference in the two video feeds.

In one embodiment, the software may automatically identify and map the pixel locations in the images for these differences corresponding to the gas plume in the infrared image. Then, the image of the gas plume (the differences shown in the infrared images from the first camera) is highlighted or colored to make it stand out in the image.

Optionally, the image processor/recorder **160** may be communicably coupled to a video monitor **162** (see FIG. **32**) and/or a database **164**, for example. The video monitor **162** may be used for an operator or inspector to view any one or more of the images or all of the images obtained while using the system **20**, for example. The database may be used as a repository or archive for the collected video images and test results. The first and second cameras **22**, **154** may be separate devices. In another embodiment, the image splitter **156**, lens **158**, first camera **22**, and second camera **154** may be integrally placed within a single portable unit. Likewise, the image processor/recorder **160** (or some portion thereof) may be placed within the same enclosure or on the same rack as the remainder of the system **20**.

FIG. **33** is a flowchart **168** showing an illustrative method that may be used for an embodiment (e.g., the embodiment shown in FIG. **32**) of the present invention. In this method of FIG. **33**, the images from both cameras may be recorded in the field and later processed in a vehicle or office. Also, using the method of FIG. **33**, the images of both cameras may be stored before being processed, even though the processing may be performed immediately thereafter (on-the-fly). The images from both cameras are compared to identify the differences (see block **170**), which may be indicative of chemical leak. Next, the differences are identified and mapped out. The mapped differences may then be added to the image from the second camera to provide a composite image. Also, when differences are identified (e.g., exceeding a predetermined number of pixels within the image, detecting movement), an alarm may be triggered to notify an operator or inspector of the suspected detection of a chemical leak.

In another method, illustrated in FIG. **34**, the infrared image from the first camera **22** and the composite image may be recorded. For example, the infrared image from the first camera may be needed for record keeping to maintain an unmodified image. However, the composite image may be preferred for reviewing by the inspections or for studying the inspections, as it may provide color coding or other visual or audio cues to help the reviewer to better identify potential leaks.

In still another method, illustrated in FIG. **35**, only the composite image may be recorded and the processing of the images may be performed as the images are collected. However, a temporary buffer memory (e.g., DRAM, MRAM) may be used during the processing.

FIG. **36** shows a simplified schematic for an alternative system **20** where the image splitter and mutual lens are not used. Thus, the first camera **22** receives its images separately from the second camera **154**. In this configuration, the second camera **154** may be a visible light camera, for example. FIG. **37** shows an illustrative flowchart **172** for a method where the system **20** of FIG. **36** may be used. The method of the FIG. **37** flowchart may be varied to provide a recording of the image(s) from the first and/or second cameras **22**, **154**. In other embodiments (not shown), additional camera(s) may be used as well (e.g., third camera). A video image from the second video camera **154** may be shown within a video image from the first camera **22** (picture-in-picture) to provide a reference view (e.g., full color visible light image) for the infrared image from the first camera **22**.

FIG. **38** shows an illustrative flowchart **174** for a method of an embodiment of the present invention. In this method, an alarm may be triggered if the comparison of images from the first and second cameras shows sufficient differences above a predetermined threshold (e.g., area of pixels, number of pixels, number of pixels per area, etc.) or movement in the image from the first camera that is not in the image from the second camera.

In another embodiment, one stationary-mounted camera (e.g., in an engine room) may be used. Often in certain areas of a plant there is rarely movement (e.g., no people moving about the room most times) in the room (other than unseen internal parts). In such embodiment, the image may be monitored by hardware or a computer system to detect movement in the image. Because the image is an infrared image taken with an infrared camera system of an embodiment, the movement may be caused by a chemical leak. Thus, the image may be continuously or periodically monitored for movement automatically. An alarm may be triggered when movement is detected to alert an operator to the suspected leak. Then, the operator may view the video image (past or present) to see if there is an actual leak.

In accordance with another aspect of the present invention, a passive infrared camera system adapted to provide a visual image of a chemical emanating from a component having the chemical therein, is provided. The passive infrared camera system includes a lens, a refrigerated portion, and a refrigeration system. The refrigerated portion includes therein an infrared sensor device adapted to capture an infrared image from the lens, and an optical bandpass filter located along an optical path between the lens and the infrared sensor device, wherein at least part of a pass band for the optical bandpass filter is within an absorption band for the chemical. The refrigeration system is adapted to cool the refrigerated portion of the infrared camera system.

The refrigeration system may include a chamber adapted to retain liquid nitrogen, for example. As another example, the refrigeration system may include a closed-cycle Stirling cryocooler. The refrigeration system may include a cryocooler system adapted to cool the infrared sensor device and the optical bandpass filter to a temperature below about 100 K. The passive infrared camera system is preferably portable and further includes a battery adapted to provide power for the infrared camera system during use of the infrared camera system. The passive infrared camera system may include a frame, a shoulder-rest portion extending from the frame, and a handle extending from the frame. The passive infrared camera system preferably includes a flat-panel screen adapted to display images obtained by the infrared camera system during use of the infrared camera system. The passive infrared camera system may further include a light shield located proximate to the screen and adapted to at least partially shield the screen from ambient light.

The optical bandpass filter may be adapted to allow a transmittance greater than about 45% of infrared light between about 3360 nm and about 3400 nm to pass therethrough, for example. As another example, the optical bandpass filter may be adapted to allow a transmittance greater than about 45% of infrared light between about 3350 nm and about 3390 nm to pass therethrough. The pass band of the optical bandpass filter may have a center wavelength located between about 3360 nm and about 3400 nm, for example. As another example, the pass band of the optical bandpass filter may have a center wavelength located between about 3375 nm and about 3385 nm, wherein the bandpass filter is adapted to allow a transmittance greater than about 80% of infrared light between about 3365 nm and about 3395 nm to pass therethrough, wherein the bandpass filter comprises a silicon dioxide substrate, and wherein the pass band has a full width at half maximum transmittance that is less than about 80 nm. As yet another example, the pass band of the optical bandpass filter may have a center wavelength located between about 3340 nm and about 3440 nm, wherein the bandpass filter is adapted to allow a transmittance greater than about 70% at the center wavelength, and wherein the pass band has a full width at half maximum transmittance that is less than about 100 nm. As still another example, the pass band of the optical bandpass filter may have a center wavelength between about 3360 nm and about 3380 nm, wherein the bandpass filter is adapted to allow a transmittance greater than about 70% at the center wavelength, and wherein the pass band has a full width at half maximum transmittance that is less than about 100 nm.

The infrared sensor device may include an Indium Antimonide focal plane array, wherein the focal plane array is enclosed in an evacuated Dewar assembly. The pass band may have a full width at half maximum transmittance that is less than about 600 nm, for example. As another example, the pass band may have a full width at half maximum transmittance that is less than about 400 nm. As yet another example, the pass band may have a full width at half maximum transmittance that is less than about 200 nm. As still another example, the pass band may have a full width at half maximum transmittance that is less than about 100 nm. The pass band for the optical bandpass filter may be located between about 3100 nm and about 3600 nm, for example. As another example, the pass band for the optical bandpass filter may be located between about 3200 nm and about 3500 nm. As yet another example, the pass band for the optical bandpass filter may be located between about 3300 nm and about 3500 nm. The pass band for the optical bandpass filter may have a center wavelength located within the absorbance band for the chemical.

The component being inspected may be a pipe, a compressor, an engine, a valve, a container, a tank, a switch, a reservoir, a fitting, a connector, a hose, a flare, an exhaust outlet, a machine, a vent for a blow-off valve, or combinations thereof, for example. The refrigerated portion may be defined by an interior of a Dewar container. The chemical may be methane, ethane, propane, butane, hexane, ethylene, propylene, acetylene, alcohol, ethanol, methanol, xylene, benzene, butadiene, formaldehyde, acetone, gasoline, diesel fuel, or combinations thereof, for example. The chemical may be petroleum, petroleum by-product, volatile organic compound, volatile inorganic compound, or combinations thereof, for example. The chemical may include a hydrocarbon, for example. As another example, the chemical may include methane, wherein the absorption band is at least partially located between about 3100 nm and about 3600 nm, wherein the pass band is located between about 3100 nm and about 3600 nm. The chemical may include methane, wherein the absorption band is at least partially located between about 7200 nm and about 8200 nm, wherein the pass band is located between about 7200 nm and about 8200 nm, for example. As yet another example, the chemical may include sulfur hexafluorine, wherein the absorption band is at least partially located between about 10400 nm and about 10700 nm, wherein the pass band is located between about 10400 nm and about 10700 nm. As still another example, the chemical may include ethylene, wherein the absorption band is at least partially located between about 3100 nm and about 3500 nm, wherein the pass band is located between about 3100 nm and about 3500 nm. The chemical may include ethylene, for example, wherein the absorption band is at least partially located between about 10400 nm and about 10700 nm, wherein the pass band is located between about 10400 nm and about 10700 nm. As another example, the chemical may include propylene, wherein the absorption band is at least partially located between about 3100 nm and about 3600 nm, wherein the pass band is located between about 3100 nm and about 3600 nm. As yet another example, the chemical may include propylene, wherein the absorption band is at least partially located between about 10000 nm and about 11500 nm, wherein the pass band is located between about 10000 nm and about 11500 nm. As still another example, the chemical may include 1,3 butadiene, wherein the absorption band is at least partially located between about 3100 nm and about 3200 nm, wherein the pass band is located between about 2900 nm and about 3200 nm. As a further example, the chemical may include 1,3 butadiene, wherein the absorption band is at least partially located between about 9000 nm and about 12000 nm, wherein the pass band is located between about 9000 nm and about 12000 nm.

The passive infrared camera system may include a video recording device adapted to record images obtained by the infrared camera system during use of the infrared camera system. The infrared camera system may be non-radiometric. The infrared camera system is preferably portable and non-radiometric.

In accordance with yet another aspect of the present invention, a passive infrared camera system adapted to provide a visual image of a chemical emanating from a component having the chemical therein, is provided. The passive infrared camera system includes a lens, a refrigerated portion, and a refrigeration system. In this case, the refrigerated portion includes therein an infrared sensor device adapted to capture an infrared image from the lens, and an optical bandpass filter located along an optical path between the lens and the infrared sensor device, the optical bandpass filter having a pass band with a full width at half maximum transmittance being less than about 600 nm, wherein at least part of the pass band for the optical bandpass filter is within an absorption band for the chemical. The refrigeration system is adapted to cool the refrigerated portion of the infrared camera system.

In accordance with still another aspect of the present invention, a passive infrared camera system adapted to provide a visual image of a chemical emanating from a component having the chemical therein, is provided. The passive infrared camera system includes a lens, a refrigerated portion, and a refrigeration system. In this case, the refrigerated portion includes therein an infrared sensor device adapted to capture an infrared image from the lens, and an optical bandpass filter located along an optical path between the lens and the infrared sensor device, wherein a pass band for the optical bandpass filter is located between about 3100 nm and about 3600 nm. The refrigeration system is adapted to cool the refrigerated portion of the infrared camera system.

In accordance with a further aspect of the present invention, a passive infrared camera system adapted to provide a visual image of a chemical emanating from a component having the chemical therein, is provided. The passive infrared camera system includes a lens, a refrigerated portion, a refrigeration system, and a battery. The refrigerated portion includes therein an infrared sensor device adapted to capture an infrared image from the lens, and an optical bandpass filter located along an optical path between the lens and the infrared sensor device, wherein at least part of a pass band for the optical bandpass filter is within an absorption band for the chemical. The refrigeration system is adapted to cool the refrigerated portion of the infrared camera system. The battery is electrically coupled to the infrared camera system, the infrared camera being adapted to be powered by the battery during use of the chemical leak inspection system.

In accordance with another aspect of the present invention, a portable chemical leak inspection system that includes a passive infrared camera system adapted to provide a focused visual image of a chemical emanating from a component having the chemical therein, is provided. The passive infrared camera system includes a lens, a refrigerated portion, and a refrigeration system. The refrigerated portion includes therein an infrared sensor device adapted to capture an infrared image from the lens, and an optical bandpass filter located along an optical path between the lens and the infrared sensor device, wherein at least part of a pass band for the optical bandpass filter is within an absorption band for the chemical. The refrigeration system is adapted to cool the refrigerated portion of the infrared camera system. The portable chemical leak inspection system also includes a battery, a frame, a shoulder-rest portion, and a handle. The battery is electrically coupled to the infrared camera system, the infrared camera being adapted to be powered by the battery during use of the chemical leak inspection system. The frame is attached to the infrared camera system. The shoulder-rest portion extends from the frame. And, the handle extends from the frame.

In accordance with yet another aspect of the present invention, a portable chemical leak inspection system that includes a passive infrared camera system adapted to provide a focused visual image of a chemical emanating from a component having the chemical therein, is provided. The passive infrared camera system includes a lens, a refrigerated portion, and a refrigeration system. In this case, the refrigerated portion includes therein an infrared sensor device adapted to capture an infrared image from the lens, and an optical bandpass filter located along an optical path between the lens and the infrared sensor device, wherein a pass band for the optical bandpass filter is located between about 3100 nm and about 3600 nm, and wherein the pass band has a full width at half maximum transmittance that is less than about 600 nm. The refrigeration system is adapted to cool the refrigerated portion of the infrared camera system. The portable chemical leak inspection system also includes a battery, a frame, a shoulder-rest portion, and a handle. The battery is electrically coupled to the infrared camera system, the infrared camera being adapted to be powered by the battery during use of the chemical leak inspection system. The frame is attached to the infrared camera system. The shoulder-rest portion extends from the frame. And, the handle extends from the frame.

In accordance with still another aspect of the present invention, a portable passive infrared camera system adapted to provide a focused visual image of a chemical emanating from a component having the chemical therein, is provided. The infrared camera system includes a lens, a Dewar container, and a refrigeration system. The Dewar container defines a refrigerated portion therein. The refrigerated portion includes therein an infrared sensor device having an array of sensors adapted to receive an infrared image from the lens and adapted to generate electrical signals corresponding to the infrared image, and an optical bandpass filter located along an optical path between the lens and the infrared sensor device, wherein a pass band for the optical bandpass filter is located between about 3100 nm and about 3600 nm, and wherein the pass band has a full width at half maximum transmittance that is less than about 600 nm. The refrigeration system is adapted to cool the refrigerated portion.

In accordance with a further aspect of the present invention, a portable passive infrared camera system adapted to provide a focused visual image of a chemical emanating from a component having the chemical therein, is provided. The infrared camera system includes a lens, a Dewar container, and a refrigeration system. The Dewar container defines a refrigerated portion therein. In this case, the refrigerated portion includes therein an infrared sensor device having an array of sensors adapted to receive an infrared image from the lens and adapted to generate electrical signals corresponding to the infrared image, and an optical bandpass filter located along an optical path between the lens and the infrared sensor device, wherein a pass band for the optical bandpass filter is located between about 3200 nm and about 3500 nm, wherein the pass band has a full width at half maximum transmittance that is less than about 80 nm, and wherein the pass band has a center wavelength located between about 3320 nm and about 3440 nm. The refrigeration system is adapted to cool the refrigerated portion.

Although embodiments of the present invention and at least some of its advantages have been described in detail, it should be understood that various changes, substitutions, and alterations can be made herein without departing from the spirit and scope of the invention as defined by the appended claims. Moreover, the scope of the present application is not intended to be limited to the particular embodiments of the process, machine, manufacture, composition of matter, means, methods, and steps described in the specification. As one of ordinary skill in the art will readily appreciate from the disclosure of the present invention, processes, machines, manufacture, compositions of matter, means, methods, or steps, presently existing or later to be developed, that perform substantially the same function or achieve substantially the same result as the corresponding embodiments described herein may be utilized according to the present invention. Accordingly, the appended claims are intended to include within their scope such processes, machines, manufacture, compositions of matter, means, methods, or steps.

What is claimed is:

1. A system for producing a visible image of a leak of any one or more chemicals of a group of chemicals, the leak emanating from a component, including:

a passive infrared camera system including:

a lens assembly including a lens;

a refrigerated portion including an interior;

an infrared sensor device located in the interior of the refrigerated portion;

a single filter configuration located in the interior of the refrigerated portion and including an optical bandpass filter fixed along an optical path between the lens assembly and the infrared sensor device;

a refrigeration system that can cool the interior of the refrigerated portion;

wherein at least part of the pass band for the single filter configuration is within an absorption band for each of the chemicals; and

wherein the aggregate pass band for the single filter configuration is at least about 100 nm; and

a processor that can process a signal representing the filtered infrared image captured by the infrared sensor device to produce a visible image of the chemical emanating from the component under variable ambient conditions of the area around the leak.

2. The system of claim **1**, further including a recording device that can record the visible image of the leaking chemical.

3. The system of claim **2**, wherein the recorded visible image can be viewed at a time other than when recorded.

4. The system of claim **2**, wherein the recording device can record the visible image along with inspection information about the image selected from a group consisting of inspection location name, inspection location address, component name, component identification information, global positioning coordinates, a date, a time of day, an inspector's name, an inspection company's name, one or more camera system setting values, and combinations thereof.

5. The system claim **2**, further including a voice recorder that can record voice notes along with the image.

6. The system of claim **1**, wherein the passive infrared camera system further includes a display screen that can display the visible image of the leaking chemical.

7. The system of claim **1**, wherein the passive infrared camera system is powered by a battery and is portable.

8. The system of claim **1**, wherein the passive infrared camera system lens assembly includes more than one lens.

9. The system of claim **1**, wherein the passive infrared camera system lens assembly is removable.

10. The system of claim **1**, wherein the refrigerated portion is defined by a Dewar container.

11. The system of claim **1**, wherein the refrigeration system includes a closed-cycle Stirling cryocooler.

12. The system of claim **1**, wherein the refrigeration system can cool the interior of the refrigerated section to a temperature below about 100 K.

13. The system of claim **1**, wherein the processor can process the filtered infrared image captured by the infrared sensor device to produce a visible image of more than one chemical.

14. The system of claim **1**, wherein the infrared sensor device captures multiple images and the processor can process the multiple images to produce a visible video of the leak.

15. The system of claim **1**, wherein, in use, the infrared sensor device receives a filtered infrared image from the single filter configuration and converts the filtered image to an electrical signal representing the filtered infrared image.

16. The system of claim **1**, wherein the processor is part of the passive infrared camera system.

17. The system of claim **1**, wherein the processor is separate from the passive infrared camera system.

18. The system of claim **1**, wherein the image can be processed in real time.

19. The system of claim **1**, further including a transmitter that can transmit the visible image to a location remote from the passive infrared camera system.

20. The system of claim **18**, wherein the transmitter can transmit the image using at least one of a cable, a wire, a wireless communication device, a network connection, the Internet, or combinations thereof.

21. The system of claim **1**, wherein the any one or more chemicals includes one or more substances selected from the group consisting of refrigerant; fuel; water vapor; methane; ethane; propane; butane; hexane; ethylene; propylene; o-xylene; toluene; benzene; acetylene; alcohol; ethanol; methanol; xylene; benzene; formaldehyde; 1,2 butadiene; 1,3 butadiene; butadiene; acetone; gasoline; diesel fuel; petroleum; petrochemicals; petroleum by-product; volatile organic compound; volatile inorganic compound; crude oil products; crude oil by-products; a hydrocarbon; and compounds and combinations thereof.

22. The system of claim **1**, wherein the filter configuration includes more than one filter.

23. The system of claim **1**, wherein the aggregate pass band for the single filter configuration is at least about 200 nm.

24. The system of claim **1**, wherein the pass band for the filter configuration has a center wavelength located between about 3375 nm and about 3385 nm.

25. The system of claim **1**, wherein the pass band for the filter configuration has a center wavelength located between about 3340 nm and about 3440 nm.

26. The system of claim **1**, wherein the pass band for the filter configuration has a center wavelength located between about 3360 nm and about 3380 nm.

27. The system of claim **1**, wherein the pass band for the filter configuration is located between about 2900 nm and about 3200 nm.

28. The system of claim **1**, wherein the pass band for the filter configuration is located between about 3100 nm and about 3500 nm.

29. The system of claim **1**, wherein the pass band for the filter configuration is located between about 3100 nm and about 3500 nm.

30. The system of claim **1**, wherein the pass band for the filter configuration is located between about 3200 nm and about 3500 nm.

31. The system of claim **1**, wherein the pass band for the filter configuration is located between about 3300 nm and about 3500 nm.

32. The system of claim **1**, wherein the pass band for the filter configuration is located between about 3200 nm and about 3400 nm.

33. The system of claim **1**, wherein the pass band for the filter configuration is located between about 9000 nm and about 12000 nm.

34. The system of claim **1**, wherein the pass band for the filter configuration is located between about 10400 and 10700 nm.

35. The system of claim **1**, wherein the pass band for the filter configuration is located between about 10000 nm and about 11500 nm.

36. The system of claim **1**, wherein the pass band for the filter configuration is located between about 10500 nm and about 10600 nm.

37. The system of claim **1**, wherein the pass band for the filter configuration has a full width at half maximum transmittance that is less than about 600 nm.

38. The system of claim **1**, wherein the pass band for the filter configuration has a full width at half maximum transmittance that is less than about 400 nm.

39. The system of claim **1**, wherein the pass band for the filter configuration is located between about 3250 nm and about 3510 nm with a full width at half maximum less than about 250 nm.

40. The system of claim **1**, wherein the pass band for the filter configuration is located between about 3200 nm and about 3580 nm with a full width at half maximum less than about 350 nm.

41. The system of claim **1**, wherein the pass band for the filter configuration is located between about 7600 nm and about 7800 nm.

42. The system of claim **1**, wherein the pass band for the filter configuration is located between about 3200 nm and about 3500 nm with a full width at half maximum less than about 300 nm.

43. The system of claim **1**, wherein the pass band for the filter configuration is located between about 3200 nm and about 3600 nm with a full width at half maximum less than about 400 nm.

44. The system of claim **1**, wherein the filter configuration allows a transmittance greater than about 70% at the center wavelength of the pass band.

45. The system of claim **1**, wherein the aggregate pass band for the filter configuration includes a full width at half maximum transmittance that is less than about 600 nm.

46. The system of claim **1**, wherein the center wavelength of the pass band for the filter configuration is within an absorption band for one of the chemicals.

47. The system of claim **1**, wherein the center wavelength of the pass band for the filter configuration is outside an absorption band for one of the chemicals.

48. The system of claim **1**, wherein the absorption band of one of the chemicals includes a peak and the pass band for the filter configuration is centered at or close to the peak.

49. The system of claim **1**, wherein the absorption band of one of the chemicals includes a peak and the pass band for the filter configuration is not centered at or close to the peak.

50. The system of claim **1**, further including a computer programmed with image recognition software to analyze the image from the processor.

51. The system of claim **1**, wherein the passive infrared camera system is attached to or supported by a movable vehicle selected from the group consisting of a motorcycle, a car, a truck, a bicycle, a boat, a ship, a personal watercraft, a rotary wing vehicle, an airplane, a powered paraglider, an ultralight aircraft, a powered glider, a glider, a balloon, a blimp, a remotely controlled vehicle, an unmanned aerial vehicle, a satellite, and combinations thereof.

52. The system of claim **1**, wherein the passive infrared camera system is non-radiometric.

53. The system of claim **1**, wherein the infrared sensor device includes an Indium Antimonide focal plane array of at least 81,920 sensor elements.

54. The system of claim **1**, wherein the passive infrared camera system is attached to a permanently installed mount.

55. The system of claim **1**, further including more than one passive infrared camera system.

56. The system of claim **55**, wherein the passive infrared cameras are part of a network.

57. The system of claim **1**, wherein the optical bandpass filter includes a silicon dioxide substrate.

58. The system of claim **1**, wherein the refrigeration system includes a chamber adapted to retain liquid nitrogen.

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United States Court of Appeals
for the Federal Circuit

Leak Surveys, Inc. v. FLIR Systems, Inc., Nos. 2016-1299, -1300

CERTIFICATE OF SERVICE

I, Robyn Cocho, being duly sworn according to law and being over the age of 18, upon my oath depose and say that:

Counsel Press was retained by NELSON BUMGARDNER PC, attorneys for Appellant to print this document. I am an employee of Counsel Press.

On **March 9, 2016** counsel has authorized me to electronically file the foregoing **Opening Brief of Appellant, Leak Surveys, Inc.**, with the Clerk of Court using the CM/ECF System, which will serve via e-mail notice of such filing to any of the following counsel registered as CM/ECF users:

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Paper copies will also be mailed to the above principal counsel at the time paper copies are sent to the Court.

Upon acceptance by the Court of the e-filed document, six paper copies will be filed with the Court within the time provided in the Court’s rules.

March 9, 2016

/s/ Robyn Cocho
Counsel Press

CERTIFICATE OF COMPLIANCE

Pursuant to Rule 32(a)(7)(C) of the Federal Rules of Appellate Procedure, I hereby certify that I am an attorney of record on behalf of Appellant Leak Surveys, Inc. and that I personally used the "word count" feature of Microsoft Word 2010 to count the words in the foregoing Brief of Appellant Leak Surveys, Inc. identified in the Rule 32(a)(7)(B)(iii) and determined that the foregoing brief contains 13,997 words and is therefore in compliance with Rule 32(a)(7)(B)(i).

In addition, this brief complies with the typeface requirements of Federal Rule of Appellate Procedure 32(a)(5) and the style requirements of Federal Rule of Appellate Procedure 32(a)(6) because this brief has been prepared in a proportionally spaced typeface using Microsoft Word 2010 in 14-point Times New Roman.

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