Sensing Volatile Hydrocarbons in Printing Processes

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Abstract

A number of industrial processes (including printing) frequently employ liquid hydrocarbons that may become volatile when used. Even though most industrial applications provide an option for their recapture and re-condensation a reliable process for monitoring volatile hydrocarbons may be required. This paper presents a broad approach to volatile hydrocarbon sensing based on infrared absorption measurements. The demonstrated sensor prototype shows a wide range of detection capabilities ranging from a few to several thousand of ppm and a high measurement speed (a few milliseconds response time). These capabilities have been achieved at a very low cost making it an attractive alternative to commercial gaseous hydrocarbon sensors.

Introduction

Industrial processes frequently involve use of liquid hydrocarbons in a form of fuel, solvent, additives or lubricants. Some of these compounds have low enough molecular masses to become volatile when used (commonly described as Volatile Organic Compounds – VOC). In many cases industrial machinery is designed to minimize the VOC creation and its release to an outside ambient. They are often equipped with a system allowing capturing and re-liquefying the VOC for further potential use.

Use of VOC sensors may provide a number of opportunities for optimizing operation of the existing processes and for a research aimed at better future system design. For example, a real-time detection of the VOC concentration inside the operating machine may facilitate a close-loop system in which fan speeds and component temperatures are adjusted for best performance. Similarly, real-time VOC signal may be used as indicator of the normal machine operation. Corresponding needs for VOC sensing in the vicinity of the industrial machinery may provide a wide range of applications for a low cost hydrocarbon VOC sensors.

Although there are a few commercially available volatile hydrocarbons sensors, their cost and operation parameters may place them outside the aforementioned applications. This work aims at demonstrating a reliable, highly sensitive hydrocarbon VOC sensor at a low enough price that could open a number of new applications in printing and non-printing industries.

Optical sensing of volatile hydrocarbons

Presence of volatile hydrocarbons can be easily detected by monitoring their distinctive IR absorption due primarily to C-H vibration, as shown in Figure 1 for the case of isoparaffinic oil frequently used in printing processes. In particular, a strong C-H stretching band between 2800cm^{-1} and 3000 cm^{-1} in the case of aliphatic hydrocarbons and at slightly higher frequencies in the case of aromatic compounds is well suited for hydrocarbon detection. Figure 1 also presence a schematic sensor arrangement consisting of an IR source, an IR detector, and a cavity filled by ambient containing vaporous hydrocarbons.

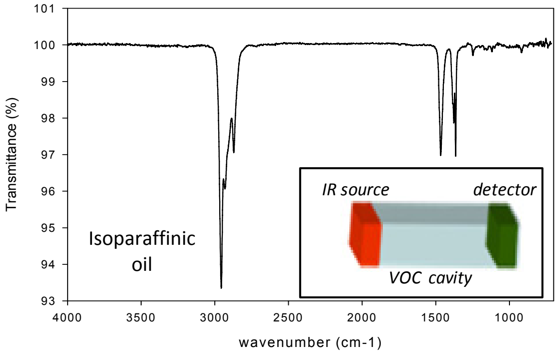

***Figure 1**. Transmittance spectrum of exemplary iosparaffiniic oil. Its primary C-H absorption band can be used for hydrocarbon sensing. Insert shows the concept of the sensor.*

This detector arrangement can be implemented by using a variety of commercially available components. It may contain a narrow band IR source, such as IR LED or a laser emitting within a frequency range corresponding to hydrocarbon absorption. A cost effective alternative may include a wide band IR source consisting of electrically heated metallic, ceramic or photonic crystal component providing IR spectrum close to a blackbody radiation. Additional advantage of this solution stems from the ability of shifting and amplifying emitted IR spectrum by simply changing the source temperature. A narrow band emission from the blackbody source is achieved by placing in front of the source an optical narrow bandpass filter centered at the hydrocarbon absorption band. Signal attenuated by VOC in the cavity can be detected with a number of commercial IR detectors that may include (in a descending cost order): a cooled photodiode, a pyroelectric element or a thermocouple, the last one usually in form of a thermopile array.

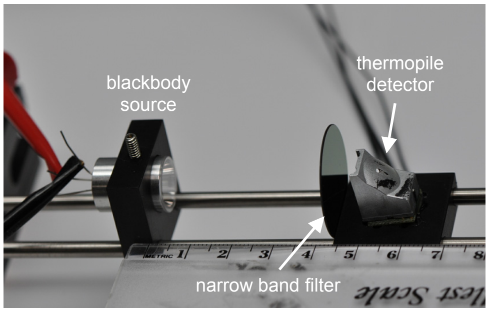

***Figure 2**. Sensor demonstrator used in this study.*

Figure 2 presents a simple sensor demonstrator used in this work. It consists of only three components: resistively heated blackbody source operating at temperature between 480°C and

500°C, thermopile detector equipped with a conical mirror, and a thin film narrow bandpass filter centered at around 2950 cm^{-1} and having FWHM of about 100 cm^{-1}. Thermopile detector has a build-in simple circuit amplifying the DC output voltage signal; this arrangement provided satisfactory quality detection for all tests described in this report. Its open structure allows to place the sensor at the desired location with tested ambient freely flowing between the source and detector. Detection sensitivity can also be optimized by changing distance between source and detector and, thus, adjusting the probed VOC volume.

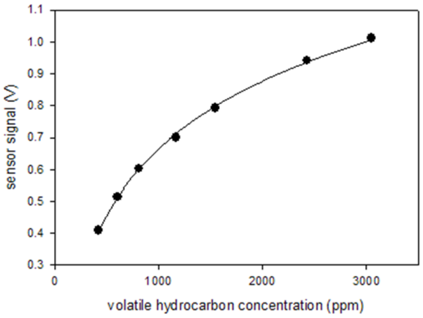

***Figure 3**. Sensor calibration curve for a commercial isoparaffic oil. Sensor detection limit is about 10 mV.*

The sensor signal was calibrated to provide concentration for a specific hydrocarbon compound. Figure 3 presents a calibration curve for one of the tested volatile isoparaffinic compounds. Sensor signal represents the amount of IR radiation reaching the detector. Increase of hydrocarbon concentration causes drop in the IR light intensity and the corresponding decrease of sensor signal. It was obtained by placing a known amount of the measured specie inside a chamber filled with dry air, and then uniformly heating the chamber to a desired target temperature in order to produce hydrocarbon vapors and bring them to a saturated concentration at this temperature while simultaneously monitoring the sensor reading. The same measurement was repeated for different target temperatures. Since the saturated vapor pressure vs. temperature correspondence is provided by the tested compound vendor, one can plot the sensor signal vs. vapor pressure curves, like the one shown in Figure 3. This measurement was also confirmed by weighting the measured compound before and after it was heated in order to determine the amount of vaporized liquid.

Experimental Results

Described sensor was tested in an experimental setup in which a controlled amount of isoparaffinic oil was slowly released at a constant rate, and allowed to volatilize to establish equilibrium between liquid and gaseous hydrocarbons. Release of the oil was timed and could be repeated as frequently as needed. These tests were designed to evaluate detection sensitivity and response speed of the aforedescribed sensor. Some of the results of this experiment are demonstrated in Figure 4.

Figure 4 show an event when a small amount of the isoparaffinic oil was released at a constant rate and allowed to vaporize for approximately 35 second. Then, for a brief time lasting about 0.5 second, the oil release rate was increased four times following by return to a slow release rate. This sequence was repeated seven times gradually increasing length of time when the high release rate was used. Each of these events resulted in easily detectable hydrocarbon vapor increase, as seen in Figure 4. This increase was not immediate; it rather built up slowly limited by the finite velocity at which vapors can move. After the experiment was completed (“end” point) sensor signal gradually raised to a level observed at the start of the experiment.

This performance matched our theoretical calculations accurately prediction the hydrocarbon vapor concentration over a wide range extending from few ppm up to several thousand ppm. Repetitive tests confirmed excellent reproducibility of the measured data. As expected, the sensor response time was of the order of few milliseconds and it was limited by the IR detector time constant. This performance significantly exceeds capability offered by commercial volatile hydrocarbon sensors.

Conclusion

It is shown that a highly sensitive sensor assembled using a very low cost, commercial component can be used for monitoring vaporous hydrocarbon compounds. Its low cost (few hundreds USD) and small response time (<10ms) makes this solution attractive for many VOC monitoring applications in both research and in industrial environment. Our experimental results and theoretical calculations assuming distance between source and

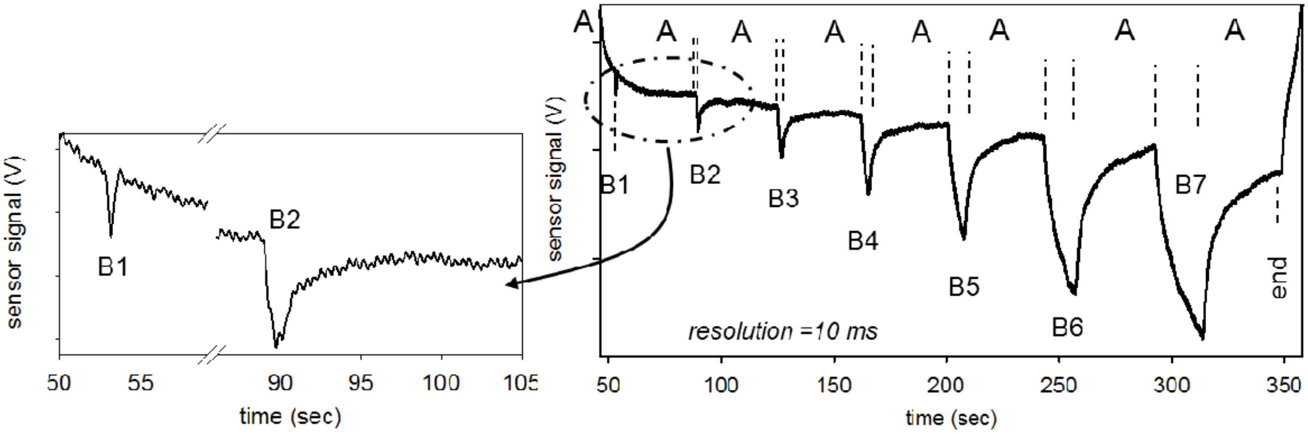

***Figure 4.** Sensor signal variation in response to changing the amount of released volatile hydrocarbons. A = slow hydrocarbon release rate for approximately 35 seconds. B1 to B7 = quadrupled hydrocarbon release rate with release time increasing from 0.5 second (B1) to 12 seconds (B7).*

detector between 2 cm and 5 cm suggest our sensor is capable of providing detection limit of less than 1 ppm and operation range from single ppm to several thousand ppm of vaporous hydrocarbons. Of course, low cost of the sensor (less than few hundred $) may provide an additional advantage when compared with commercial gaseous hydrocarbon sensors typically costing few thousands $ and having inferior performance in comparison with our solution.

Acknowledgement

The authors would like to acknowledge collaboration with Henryk Birecki. Fruitful discussions with our colleagues from the HP Indigo division are also acknowledged.

Author Biography

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Seongsik Chang is a senior research scientist in Printingand Content Delivery Laboratory (PCDL) in Hewlett Packard Laboratories. He has been primarily working on innovations in printing processes and materials for digital commercial print engines including charge roller, organic photoconductor, and environmentally friendly printers. Before joining Hewlett Packard Laboratories, Seongsik worked on research and development of integrated photonic devices with a focus on active and passive device integration. Seongsik received a Ph.D. in physics from Yale University where his focus was experimental research on optical chaos in micro-cavities. He received B.S. in physics from Seoul National University in South Korea.