

Opto-Electronic Sensor for HTF Early Leak Detection Based on Infrared Absorption

David Izquierdo^{1,*} , María Heras¹, Cristina Pelayo¹ , Adrián Peña² ,
and Marcelino Sánchez² 

¹Aragon Institute for Engineering Research (I3A), Universidad de Zaragoza, Spain

²National Renewable Energy Center of Spain (CENER), Spain

*Correspondence: David Izquierdo, d.izquierdo@unizar.es

Abstract. We propose an early leak detection sensor for HTF (Heat Transfer Fluid) leakages by measuring the absorption of infrared radiation by the HTF components. This sensor, that can be installed inside the insulation around ball joints or other elements in a Concentrated Solar Power (CSP) plant, detects leaks by sensing mid-infrared absorption at specific wavelengths. The sensor includes a reference signal to correct for external factors like temperature changes and sensor degradation. Laboratory tests have validated the sensor performance under various conditions. The sensor enhances the sustainability of solar thermal plants by providing early leak detection and is easily adjustable for different HTFs by changing the IR (Infrared) radiation sensing bands.

Keywords: HTF Leakage Sensor, CSP, HTF, IR

1. Introduction

In the constant pursuit of cleaner and more sustainable energy sources, Concentrated Solar Power (CSP) plants based on Parabolic Trough Collector (PTC) technology emerge as an innovative solution to harness solar power and convert it into usable energy, mainly electrical and thermal energy. One crucial aspect in this technique is the Heat Transfer Fluid (HTF), often a thermal oil, which plays an essential role in its operation by transferring the absorbed solar heat. However, uncontrolled HTF releases or leakages can have severe environmental consequences with a high risk of soil and water contamination near the plants [1]. Moreover, prolonged exposure to these compounds can negatively impact on local ecosystems and on the health of people living in surrounding areas. Therefore, early detection of HTF leaks is essential to minimize environmental risks and take corrective actions promptly [2]. These leaks typically occur due to the movement of the cylindrical-parabolic concentrator and are located in the moving parts such as the ball-joints that connect the collector tubes through which the HTF flows. When a leak occurs, the oil is initially released in gaseous form in a very early stage due to its operational high pressure and temperature. But the problem is that it is not easy to notice these leaks, because elements of the solar thermal plant like the ball joints are thermally enclosed into an insulation that protects the thermal loop against losses that these elements can cause. Also, the vapor that the high temperature HTF generates, once it is at ambient pressure, is colorless. Then, a leak can remain hidden for weeks until producing any external noticeable effect.

Currently, HTF leakages at CPS plants are detected by mere observation of gas clouds or condensation stains. One of the specialized real-time instrumentations for this purpose is handheld photoionization cells that result in a very non-specific detection of volatile organic compounds in the ambient [3]. Another proposal is detecting the gas plume escaping from the insulation by artificial vision using an infrared camera that is mounted on an unmanned ground (UGV) or aerial (UAV) vehicle [4]. Although these techniques are very interesting, they cannot detect the leakage in an early stage when there may be some condensed HTF inside the ball joint insulation.

We propose an early leak detection sensor for HTF leakages able to detect its gaseous form inside the insulation around ball joints or other elements in a CSP plant. The sensor is based on detecting the presence of HTF measuring the absorption of IR (Infrared) radiation inside the insulation. This IR absorption, mainly in the near- and mid-infrared regions of the electromagnetic spectrum, occurs at certain wavelengths depending on the gas chemical composition and on its concentration. Sensing the absorbance at a wavelength that corresponds with one of the absorption lines of the HTF volatile components, the device can detect the presence of this component.

Our sensor, which is under patent procedure [5], is highly sensitive, allowing leak detection at an early stage, which will significantly contribute to the operational and environmental sustainability of solar thermal plants while ensuring efficient and responsible energy production.

2. Sensor description

The HTF to be detected is the Therminol VP-1 Heat Transfer Fluid, a eutectic mixture of two organic components: 73% diphenyl oxide and 27% biphenyl. The real-time detection of these components in the surrounding area around the element that is prone to leaks constitutes the basis of our sensor of HTF leakage. The absorption curves as a function of wavelength for diphenyl oxide and biphenyl in their vapour phase [6] are shown in *Figure 1*. As can be seen, they show absorption peaks in different bands.

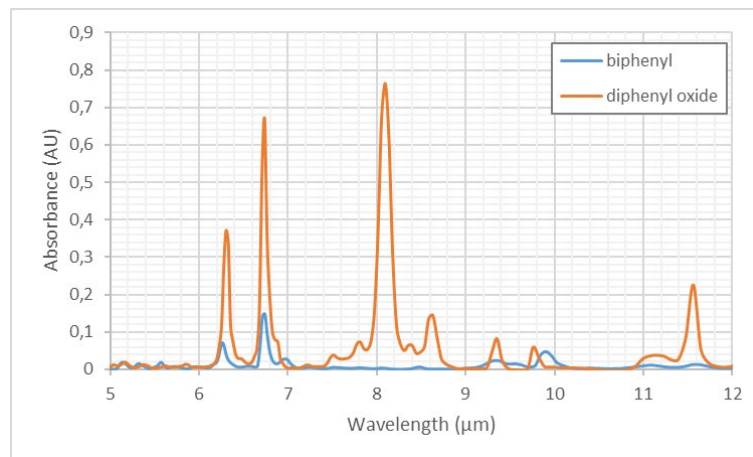


Figure 1. IR absorption spectra of the HTF components.

Diphenyl oxide shows the highest absorption peaks, with maxima at 6.3 μm, 6.7 μm and 8 μm. On the other hand, the absorption peaks of biphenyl are weaker and are located at 6.3 μm, 6.7 μm and 9.5 μm. These peaks were validated by evaporating a small sample of the HTF at around 250°C and measuring the IR spectra absorption in a laboratory setup. These measurements not only validated the absorption peaks but also the feasibility of the proposed technique.

The HTF sensor, as shown in *Figure 2*, consists of an IR source, a metallic conduit with holes, and an IR detection system. The IR source, with an emitting power of 20 mW, is a broad radiation source with an equivalent temperature of 770K and its radiation is modulated following a rectangular function at a frequency of a few hertz (5 Hz). This modulation allows to filter out the detected signals from the ambient light, which is a continuous signal, and other IR sources that can interfere with the measurements.

The metallic conduit guides the IR radiation from the IR source to the detector. This metallic pipe also has a series of holes to allow the HTF gases to enter into it. These gases will interact with the IR radiation and will absorb only some wavelengths. The sensor has been designed to be suitable for in-plant installation, and the guiding conduit has been curved to be positioned around the element to be monitored.

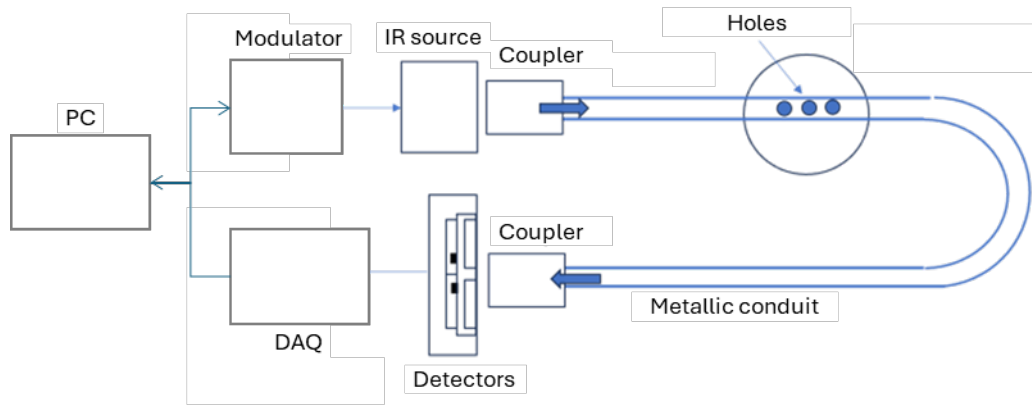


Figure 2. Schematic of the HTF sensor.

In order to connect the metallic conduit with the emission and detection modules, we designed, and 3D printed, two coupling pieces. These couplers include quick connectors, which facilitate the connection and disconnection with the pipe and guarantee its sealing and liquid tightness. KBr optical windows have been also included to protect electro-optical elements from the gas in the tube and to seal the connection to the conduit.

The detection system is based on two thermopiles with optical filters that detect only two IR narrow bands. One detection band will be centered at 8 μm to detect the absorption peak of the HTF and the other band will be at 10 μm , where there is no absorption peak, and which will be used as a reference signal. This way, measurements at 8 μm will be corrected to cancel/eliminate variations in the light source or in guiding conditions that are measured with the 10 μm filter, thus distinctively detecting only the presence of gas.

The detected two signals are digitized by a Data Acquisition Card (DAQ) and digitally processed in a Personal Computer (PC). The Digital Signal Processing (DSP) implemented in the PC is based on lock-in amplification algorithms to amplify and clean the two detected signals, filtering out ambient light, filtering out noise, eliminating the influence of continuous signals and other interfering frequencies, while amplifying the desired signals. Finally, the ratio between the two signals (sensing and reference) is calculated and when the ratio between the sensing signal and the calibration or reference signal exceeds a threshold level, it is determined that the thermally insulated component leaks HTF.

3. Results

To validate the sensor and the technique, a laboratory experimental setup has been assembled, as can be seen in *Figure 3*. The metallic conduit in this setup is an 8 mm diameter and

100 cm length shiny aluminum tube with a series of six holes, each with a diameter of 3 mm. Close to these holes, a small sample of the HTF is placed in a crucible and a laboratory heater is used to generate evaporated gas at a temperature of 250°C, approximately.

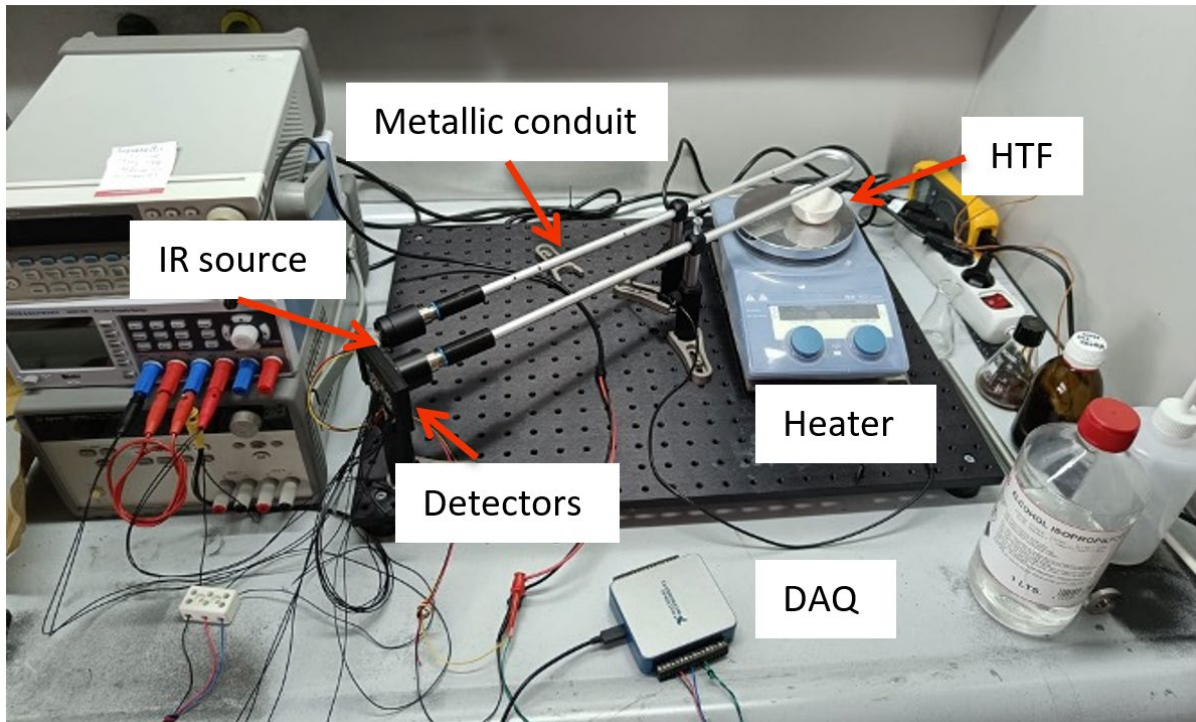


Figure 3. Photograph of the laboratory experimental setup used for sensor validation.

As can be seen in *Figure 3*, a mechanical housing was designed and fabricated on a 3D printer in order to integrate all the necessary components of the detection system. This housing, connected with the detection coupler, fixes and protects the elements and electronics for the two thermopiles, sensing and reference. The two thermopiles are located behind the respective optical filters without occlusion, so that the maximum amount of IR light from the light guide reaches them, enhancing sensor sensitivity.

Figure 4.a illustrates the time response of the measured signals, sensing and reference, when simulating an HTF leakage in laboratory facilities. The graph shows that, in the first instants, without the presence of the gas, the sensing and reference signals are almost constant and with amplitudes of 55 mV and 65 mV, respectively. When gas is introduced, after 100 seconds, the sensing signal presents a fast response to the leakage, lower than 30 seconds, reaching a level of 5 mV, the lower limit of the system. This reduction, equivalent to approximately one absorbance unit, is associated with the absorption of the gas in the 8 μm band. Meanwhile, the reference signal also drops to a level of 35 mV when the gas is introduced. Theoretically, the reference signal should remain constant because the gas does not absorb light at 10 μm , but this effect could be associated to scattering produced by the gas or to changes in the guiding conditions inside the metallic conduit, especially when gas concentration is high.

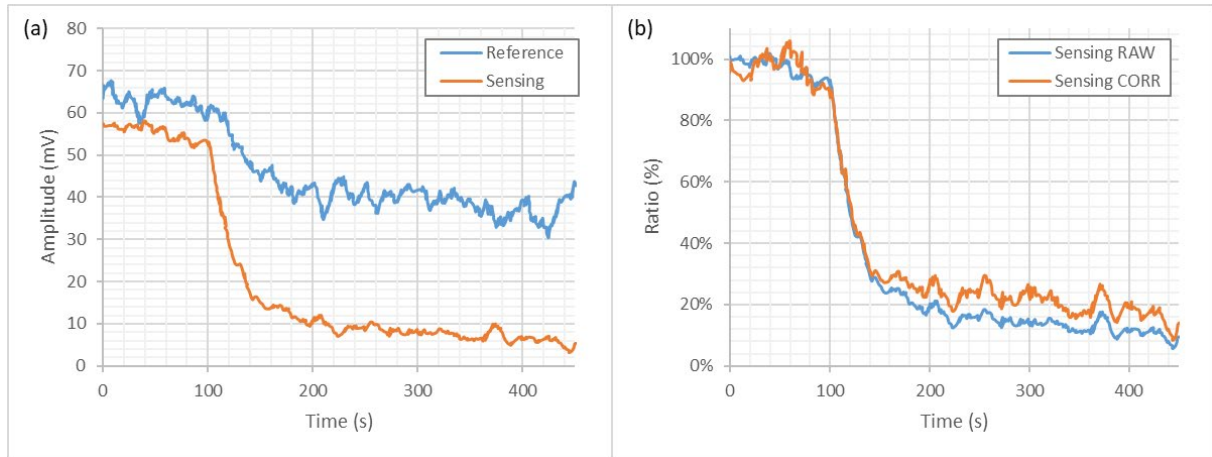


Figure 4. Measured signals time response of the sensor under HTF presence (a) and their ratio (b).

To better analyze the results obtained in the experiment, two ratios have been calculated: sensing raw is the ratio between the sensing signal and a reference level corresponding to the absence of gas; and sensing corr is the one that includes a correction using the reference signal. These ratios, as can be seen in *Figure 4.b*, remain constant at a value of approximately 90% in the absence of gas, while in the presence of gas, they drop quickly to reach, in this instance, 24% for the corrected ratio. For a real application of the sensor, a threshold in the corrected ratio should be established to alarm the presence of an HTF leakage.

If the sensor did not have the correction with the reference signal at 10 μm , the sensing raw ratio in the example shown in *Figure 4.b* is 15%. This lower value could deceive us, because it is lower than the corrected one and it appears to be better, but in fact it is the opposite, this ratio is wrong because it includes effects that attenuate the signal, as commented before, but are not related with the presence of gas. These effects would be falsifying the real gas absorption measurement by a factor of almost 2. Without the reference channel, this kind of phenomena could generate false alarms or false negatives.

These results indicate on the one hand that the corrected ratio between the sensing and the reference signals is a good indication of the presence of gas, but the system may be susceptible to saturation if the gas concentration is very high. As high gas concentration levels are not expected at an early leak stage, we can conclude that the sensor system and the measurement strategy are valid, although the dynamic range should be improved to be able to measure the presence of gas better and without so much noise.

These results indicate that the sensor can be considered preliminarily validated. The inclusion of a second detection band, acting as a reference signal, allows the compensation and correction of drifts in the measurement due to external factors.

4. Conclusions

An early leak detection sensor for HTF leakages has been proposed. The sensor is based on the measurement of the absorption of infrared radiation by the HTF components present in the surrounding area around the element that is prone to leaks. The device is capable of online monitoring the leak state and detecting HTF leakage by sensing the mid-infrared IR absorption of the HTF components in the surrounding area at a specific wavelength that corresponds with one of the absorption lines of the HTF volatile components. The sensor includes a reference signal for long-term correction of potential IR variations, which may be caused by external factors, such as temperature fluctuations or mechanical and electro-optical degradation of the sensor, achieving great reliability in the measurement and HTF leak detection.

In laboratory tests, the measurement concept of the sensor has been validated, including the basic mechanical, electronic and optical components. The sensor has been tested under a variety of conditions to ascertain its time response, ambient temperature tolerance, auto-reference capabilities, sensitivity, and behaviour under saturation conditions.

The sensor offers early leak detection by detecting the HTF volatile components, which will contribute significantly to the operational and environmental sustainability of solar thermal plants while ensuring efficient and responsible energy production. Finally, the reduced number and size of the sensor components allow a high degree of integrability on field of the sensor, even inside the insulation of key elements along the thermal loop, and it can be easily re-configured, adjusted and optimised for different HTFs, only by selecting the appropriate IR filters centred on the absorption lines of the components to be detected.

Data availability statement

For more information about the data used, contact the authors.

Author contributions

Conceptualization: David Izquierdo and Marcelino Sánchez

Data curation: María Heras

Funding acquisition: Marcelino Sánchez

Investigation: David Izquierdo, María Heras and Cristina Pelayo

Project administration: Marcelino Sánchez

Resources: Cristina Pelayo

Writing – original draft: David Izquierdo

Writing – review & editing: David Izquierdo, Marcelino Sánchez and Adrián Peña

Competing interests

The authors declare that they have no competing interests.

Funding

Part of this work was funded by grant CPP2021-009047, funded by MCIN/AEI/10.13039/501100011033 and by the European Union "NextGenerationEU"/PRTR.

References

- [1] K. F. Beckers et al., "Addressing solar power plant heat transfer fluid degradation: Experimental measurements of hydrogen transport properties in binary eutectic biphenyl/diphenyl ether", *Solar Energy*, vol 173, pp. 304-312, 2018, doi: <https://doi.org/10.1016/j.solener.2018.07.066>.
- [2] C. Prieto et al., "Evaluation of cross-contamination in indirect thermal storage system in concentrated solar plants", *Renewable Energy*, vol 212, pp. 492-499, 2023, doi: <https://doi.org/10.1016/j.renene.2023.05.081>.

- [3] C.E. Gamble et al., "Heat transfer fluid leaks: break the fire triangle", Chemical Engineering journal, December 2010 issue
- [4] A. Ibarguren et al., "Thermal Tracking in Mobile Robots for Leak Inspection Activities", Sensors, vol 13, pp. 13560-13574, 2013, doi: <https://doi.org/10.3390/s131013560>.
- [5] A HTF Leak Detector Device and Method for Detecting HTF Leaks in a Solar Thermal Installation, European Patent EP24382930.
- [6] NIST Chemistry WebBook; NIST Standard Reference Database Number 69, Eds. P.J. Linstrom and W.G. Mallard, National Institute of Standards and Technology, Gaithersburg MD, 20899, doi: <https://doi.org/10.18434/T4D303>.