



## IR THERMOGRAPHY APPLICATION FOR VACUUM LEAK DETECTION OF ABSORPTION CHILLER IN PETROCHEMICAL PLANT

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### ABSTRACT

Vacuum pressure is the main factor of sustaining absorption chiller performance and reliability. Any leaks reduce chiller machine capability to produce chilled water supply that comply with petrochemical plant demand and temperature requirement. This study explores possibilities of IR thermography application as a systematic detection method of vacuum leak at absorption chiller. The method combines basic process knowledge of absorption chiller and IR thermography theory in order to identify and verify vacuum leak location. It also considers requirement and demand of petrochemical plant operating nature that requires quick and reliable leak detection method. From experimental result, it shows that IR thermography can be applied as vacuum leak detection method provided that special consideration need to be made on surface emissivity and temperature gradient between target surface and ambient environment.

**Keywords:** IR thermography, vacuum leak, petrochemical plant.

### INTRODUCTION

Absorption chiller is designed to produce 15 to 20 °C chilled water as part of petrochemical plant utility system. It uses Lithium Bromide as absorption fluid and demineralized water as refrigeration fluid in a closed vacuum environment. Its vacuum pressure, approximately less than 20 mBar absolute or equivalent to 2 kPa or 0.0197 atm is required to permit water to vaporize at low saturation temperatures. As mentioned in [1], loss of vacuum reduces chiller capacity, efficiency and quickly leads to corrosive damage to steel compartment.

Common source of vacuum leak is due to leakage at equipment mechanical connection such as pipe flanges, threaded connections and welded points. Normally, a big leak of a vacuum system is easily noticeable as it produces loud noise and tremendous pressure increase towards atmospheric pressure. However, a small leak is hardly detected and yet it can gradually cause pressure increase that will reduce absorption chiller efficiency. Traditionally, soap bubble leak test is preferred as an easy detection method of vacuum leak. However, detection of small leak is time consuming and will depend greatly on the attentiveness of the inspector. It requires close and tedious observation at every potential leak point. It is important to come out with a quick and practical vacuum leak detection method in order to sustain reliability of absorption chiller. Hence, unnecessary production loss of petrochemical plant due to chilled water supply interruption can be avoided.

### RELATED WORK

Typical pressures in a Lithium Bromide absorption chiller are less than atmospheric pressure. According to [4], the pressures are determined by vapor pressure characteristic of the working fluids. For example, vaporizing water at 5 °C require process pressure of 0.872 kPa or approximately 0.009 atm or 9 mBar absolute. This extremely low pressure causes absorption chiller technology to be very sensitive to leaks. Air leak affects

chiller performance and becomes corrosive catalyst to the equipment.

There are several vacuum leak detection methods practiced but not really suitable for petrochemical industry environment such as application of mass spectrometer. It is explained in [8] that it can be used as a detector of tracer gas such as helium which is allowed to flow through a leak spot. Even though mass spectrometer is regarded as the most sensitive leak detector available [9], it is also well known as an expensive technology. While mass spectrometer can be tuned to detect any specific gas based on their molecular weight, other similar method is to couple specific tracer gas with its detector. As also mentioned in [9], hydrogen and oxygen gas can be performed as tracer gas and their specific gas detector can be utilized to locate leak location. Ammonia can also function as tracer gas. Leak of ammonia can be detected chemically by applying a cloth or filter paper moistened with mercury compound solution with is turned black by ammonia gas. However, ammonia and mercury are hazardous substances that require safety-handling consideration. Leak hunting by using soap water test on a pressurized absorption chiller with any gas above atmospheric pressure is also practiced by industry practitioners [6]. Nevertheless, any requirement to pressurize absorption chiller with tracer gas will have to drain out Lithium Bromide from the equipment. Prolong outage period of absorption chiller is not a preferable option for any petrochemical plant.

According to [6], application of spark-coil test can also function as vacuum leak detection method. It uses a Tesla coil to produce high-voltage and high frequency discharge at metal probe tip. Leakage is identified by spreading of discharge over the test area. However, this procedure is limited to glass system only. Besides, exposure of high voltage discharge in a potential flammable hydrocarbon gas release environment of petrochemical plant will not be tolerated.



Other quantitative vacuum leak measurement practices are thermal conductivity gauge method [6], IR absorption measurement of gas molecules in vacuum system [11], tuning fork crystal chip pressure sensor [7] and vacuum pressure gauge such as Pirani and Penning gauge [9]. However, they only provide us measurement on leak rate of the vacuum system and do not locate the leakage location.

On the other hand, indirect leak detection method such as thermography works on the principle of air flow affects surface temperature. By referring to [10], if gas enters from atmospheric condition into a lower pressure reservoir such as vacuum condition, it expands, cools down and chills the leak point. Therefore, vacuum leak is represented by cold spot in an IR thermography image. Due to heat conduction, the temperature different propagates dependent on thermal conductivity of the material. Metal conducts heat well, whereas plastic conducts heat less. This is why cold spot of vacuum leak is easier to be detected on metal surface compared to plastic surface.

## METHODOLOGY

This study consists of four methodology stages; which are problem verification, data acquisition, image analysis and data verification.



**Figure-1.** Study methodology.

### Problem verification

Vacuum loss in an absorption chiller can be caused by two reasons; leak that allow air entering into the vacuum system and generation of incondensable gas. It is important to verify source of leak before proceed to the next stage.

Normally an absorption chiller is equipped with hydro ejector system and vacuum pump to sustain its vacuum pressure. Hydro ejector system and vacuum pump are used to remove incondensable gas from the vacuum system. The gas is generated from chemical reaction inside absorption chiller. The incondensable gas is eliminated by running hydro ejector system and vacuum pump. Therefore, the required vacuum pressure can be achieved.

If source of vacuum loss is coming from leakage, the desired vacuum pressure will be hardly achieved even though by running hydro ejector system and vacuum pump. The absorption chiller vacuum pressure measurement can be monitored from pressure transmitter connected to plant Distributed Control System (DCS) and can be verified by local pressure gauges. By completing this stage, it can be deduced that high possibility of vacuum loss is coming from leakage.

### Data acquisition

The leak search was strategized by identifying all potential and possible locations at absorption chiller. All piping and equipment connections such as pipe flanges and threaded connections for auxiliary equipment such as gauges and transmitters were identified.

The image source used during the study was a thermal imaging camera Fluke IR Flexcam Ti40. The camera has thermal sensitivity of  $\leq 0.09^\circ\text{C}$  at  $30^\circ\text{C}$ . The device minimum focus distance is 0.15m. It has 160 x 120-pixel resolution with digital image enhancement. The camera is also equipped with handheld strap, a full colour 1280 x 1024-pixel visible light camera and 5" large high resolution digital display that are quite useful for leak search. Recorded image can be stored into 512MB memory card that can be transferred to PC for image analysis.

There were several consideration order to get the best result out of IR thermography on vacuum leak detection. In general, absorption chiller is a combination of several heat exchangers with integrated piping and circulation pumps. We have to take note on material layer type of potential leak location since it has significant effect on emissivity. In general, there are two types of material layers at absorption chiller; non-metallic and polished metallic layers.

Non-metallic layer especially paint coated piping joint has high IR emissivity property, approximately 0.95 at 300 Kelvin [3]. It tends to radiate more energy rather than reflecting IR radiation energy. It gives us the best condition for IR thermography since it provides us the closest representation of material layer's temperature. Therefore, it is important to prioritize IR thermography on non-metallic layer because it does not require any emissivity correction or compensation.

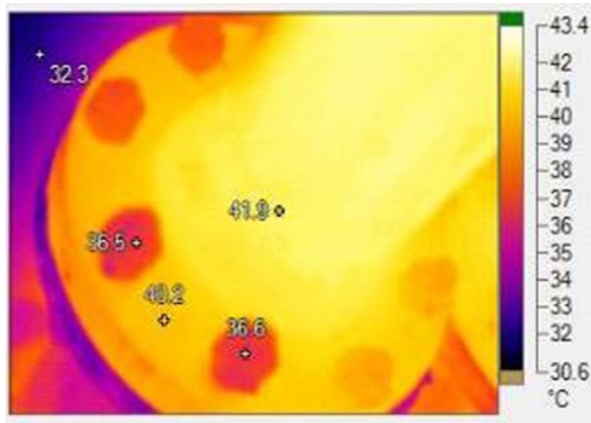
Polished metallic layers can easily be penetrated by thermal waves; hence local heat sources lying below these layers can also be detected by IR thermography. However, since due to the high reflectivity of these layers their emissivity is low, heat sources below them might remain undetected if no measures are taken to increase the emissivity [2]. Low emissivity layer such as Stainless Steel and uncoated polished Carbon Steel tend to reflect rather than radiate IR radiation. It has low emissivity approximately  $\leq 0.25$  at 300 Kelvin [3]. In order to avoid disturbing high reflective image, the polished layer has to be covered by high emissivity material and low heat resistivity such as paint and masking tape. Other alternative is to perform software based compensation of emissivity contrast in IR thermography camera [3].

### Image analysis

Vacuum leak hunt is actually looking for thermography cold spots at potential leak locations. It can be detected by manual observation on high resolution digital display feature available on Fluke IR Flexcam Ti40 camera. Temperature spot of several locations in thermography image were compared in order to point out cold spot location. Temperature gradient represented by



colour tone was identified as be the main guideline of locating these cold spots as shown in Figure-2.



**Figure-2.** Sample of thermography image on Fluke IR Flexcamp Ti40 camera display.

#### Data verification

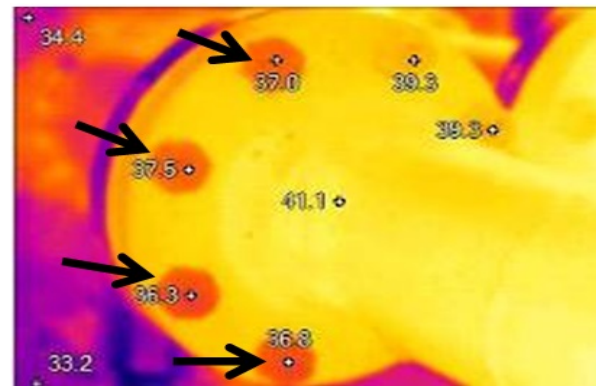
Cold spots detected by IR thermography camera were verified with soap bubble test. Apply soap bubble spray onto the targeted leak point. Bubble formation will be quickly diminished as air molecules are being pulled into the vacuum system through leak point. This requires close observation since it is important to differentiate bubbles pop due to air flow at the leak points or because of external wind factor. Normally, detectable noise is very low unless the leak size is quite big.

The next verification is to perform a quick fix on the leak point. The fix method depends on leak mechanism. For example, leak caused by loose pipe flange connection can be fixed by fastening the loosen studs and bolts. By fixing the leak, vacuum pressure will gradually improve, provided hydro ejector system and vacuum pump is running to assist the vacuuming process.

#### RESULT AND ANALYSIS

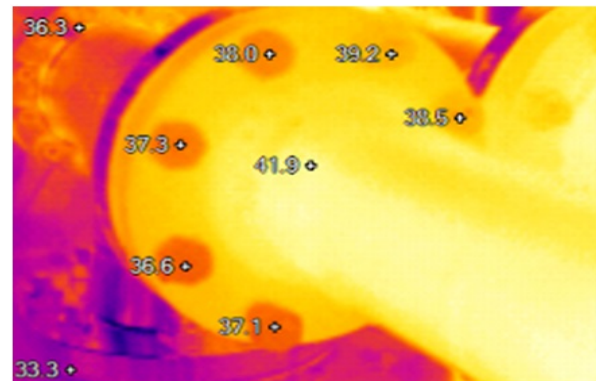
IR thermography was done during night time in order to minimize IR reflection especially for polished metallic surface. Vacuum leak search was targeted at identified potential location and prioritized was given to paint coated surfaces compared to polished metallic surfaces.

Cold spots were found on stud and bolts of a 4" pipe flange (refer to Figure-3). Based on IR thermography image, recorded temperature on the flange surface were approximately 39.5 to 40 °C. Whereas the cold spots temperature of the studs and bolts were within range between 36.4 to 37.3 °C. Emissivity value of thermography image was set at 0.95. There was no significant and noticeable air flow sound at the leak points. This was probably because the leak was too small and overwhelmed by surrounding machineries noise.

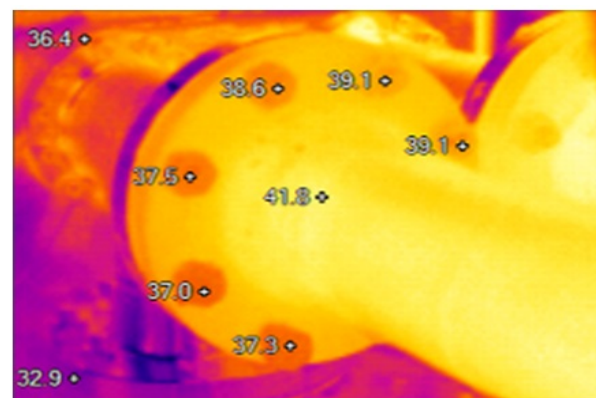


**Figure-3.** Cold spots of vacuum leak found on paint coated 4" pipe flange connection.

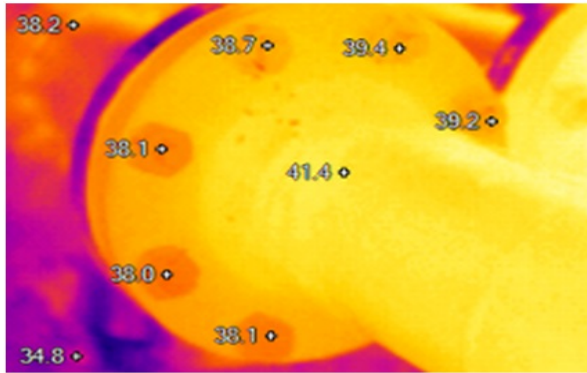
The leak points were then verified with soap bubble test. With close and attentive observation, soapy water was sprayed on the leaks points especially at pipe flange connection surface and around detected cold spots at identified stud and bolts. It was proven that bubbles were diminished and soap water was sucked into the leak points.



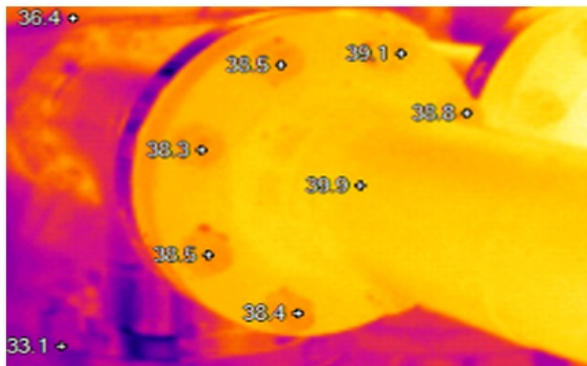
**Figure-4(a).** Cold spots condition (refer to Figure-3) 1 minute after leak was fixed.



**Figure-4(b).** Cold spots condition (refer to Figure-3) 2 minutes after leak was fixed.

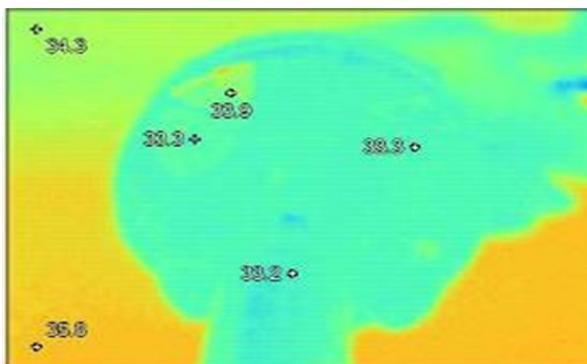


**Figure-4(c).** Cold spots condition (refer to Figure-3) 3 minutes after leak was fixed.

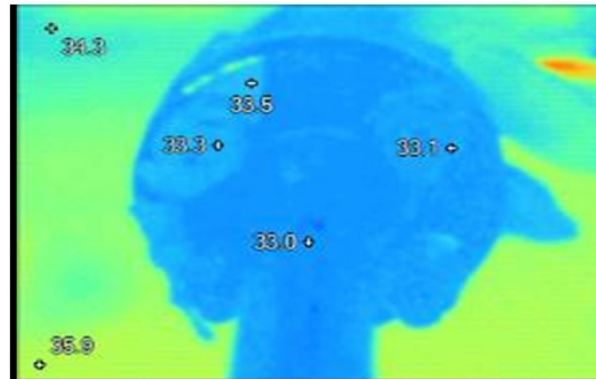


**Figure-4(d).** Cold spots condition (refer to Figure-3) 4 minutes after leak was fixed.

Quick fix was performed by fastening the identified stud bolts. The leak points were re-verified using soap bubble test to ensure the leak was completely fixed. Progress on thermography images were taken every minute up to 4 minutes after the vacuum leak was eliminated. It was observed on thermography images that cold spots were gradually disappeared and the identified stud bolts temperature were normalized and uniformed with the rest of flange surface temperature (refer to Figure-4).



**Figure-5(a).** Vacuum leak IR thermography images at polished metallic surface of 1-inch pipe flange connection with compensated emissivity = 0.95.



**Figure-5(b).** Vacuum leak IR thermography images at polished metallic surface of 1-inch pipe flange connection with compensated emissivity = 0.25.

A leak was simulated at a polished metallic surface on a 1" pipe flange connection by loosen 2 out of 4 stud bolts. None of cold spot image was observed at both compensated thermography emissivity value of 0.95 and 0.25 (refer to Figure-5). At this condition, leak was verified by soap bubble test but no obvious sound was heard. When camera compensated emissivity was set at 0.95, thermography image was not very clear. This could probably due to high reflective property of polished metallic surface. However, at a lower camera compensated emissivity value of 0.25, thermography image was improved but still unable to detect any cold spot. Average temperature recorded on the flange surface was around 33.0 to 33.4 °C.

The flange was then disengaged until vacuum leak progress to a bigger leak. Huge amount air flow was rushed into the leak point as it produced a loud hissing sound. Based on thermography images at compensated emissivity value of 0.95 and 0.25, no obvious cold spot was detected.

This result probably contributed by small temperature gradient between the leak point and flange surface temperature. Besides, the flange temperature (approximately 33.0 to 33.4 °C) was close enough to ambient temperature which approximately 35 °C. The observation point was located below a hot water heat exchanger compartment. During normal operation, the hot water temperature was set at 150 °C. Whereas, the other sample shown in Figure-3 has ambient background temperature colder than the target surface. This could be the main contributing factor of not able to detect cold spot since low emissivity factor of polished surfaced was ruled out by camera compensated emissivity feature.

## CONCLUSIONS

In conclusion, IR thermography can be applied as a quick and reliable vacuum leak detection method in petrochemical plant provided considerations to be made on two major aspects. 1) Target thermography surface shall be warmer than ambient background temperature. Leak creates cold spot on leakage surface. If cold spot



temperature is greater than the ambient temperature, it can be detected effectively by IR thermography. This can be done by either heating up the target surface of cooling down the ambient temperature. 2) To improve target thermography surface by increasing its emissivity without significant reduction in thermal conductivity property. It is recommended for to coat absorption chiller piping and connection with a thin painting layer. By doing this emissivity can be uniformed more than approximately 0.85 and therefore eliminate disturbance from rusty surface and reflectivity of polished metallic surface.

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