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Thermal Gradient Pattern of Shallow Pitting Via Active Thermography-Water and Steam

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Abstract: Pipelines are extensively used worldwide to transport water, oil and gas. Wall thinning or pits can be produced in the internal of the pipe after being used for a certain period of the time due to some factor such as erosion-corrosion and pitting corrosion. This problem concern lots of company in various industry because leakage of pipe cause system failure, hazard at workplace and increase of maintenance cost. This study detected internal wide and shallow pitting of pipe using infrared thermography. ASTM A106 Grade B carbon steel pipe test specimen was drill with five similar size defects shallow pitting within different depth. The result found that all defects appear at 90°C temperature exposure, while only four defects appear at 70°C and 80°C of temperature exposure. This is due to the higher temperature introduced into the pipe, the higher temperature gradient could be observed. Introducing a 90°C of heat source will produce the shortest time for the spot to appear while for 70°C take the longest time. Image analysis software assists to conclude that the defect areas are within 146% to 222% larger than the actual size at pipe.

1. Introduction

Pipe failure caused by inner corrosion defects is one of the risk for the unscheduled shutdown of a plant. According to National Association of Corrosion Engineers (NACE), corrosion can be defined as the deterioration of a substance or its properties due to reaction with its environment. Erosion-corrosion is the acceleration or increment in the rate of decay or attack on a metal due to relative movement between a corrosive fluid and the surface of metal [1]. Generally, pitting corrosion is the most disastrous form of corrosion because it is very difficult to predict [2]. Pitting corrosion is a form of localized attack on metal surface confined to a point that takes the form of cavities. CC Technologies Laboratories, Inc., has come to conclusion where the annual direct cost of corrosion in United States are 276 billion dollar [3] based on their observation from 1999 to 2001. A study of corrosion was conducted in China estimated the annual cost at 498 billion Yuan [4]. Therefore, inspection of the pipe need to be conducted in order to reduce the risk of possible higher cost. However there is an issue regarding cost for an inspection to be conducted because pipelines are usually very long and may extend to several miles. The implication of corrosion on these critical pipes is insurmountable. Corrosion causes pipe deterioration, leading to damage resulting in leakages. These leakages often cause fires, massive explosions and fatalities [5]. Any unscheduled breakdown will lead to high maintenance cost [6]. One of the alternative methods to inspect pipeline is by using Infrared Thermography method. Thermography inspection provide plentiful of information with infrared images and reports.

Studies conducted by Shen and Li [7] reported that infrared thermography technology can easily detect corrosion defect within 10mm diameter or bigger and depth for at least 40% of wall thickness. Highest surface temperatures were emerged from the obtained infrared thermal image when the penetration of erosion defect is deeper [8]. Thus, infrared thermography technique is a suitable method to locate pitting and size estimation could be analyzed.

2. Methodology

As to perform the study, a 1.0 m height of ASTM A106 Gr.B carbon steel pipe was used. The 6 inches diameter pipes with 10mm thickness were drilled at the inner surface with five similar size defects but different depth. Figure 1 shows the carbon steel pipe induced with an artificial defect while Table 1 lists the depth of the shallow pitting.

In general, infrared thermography techniques can be categorized into passive and active thermography. In passive thermography analysis, propagation of natural heat in the structure are due to its normal operation is scanned by infrared camera, whereby no heat source is

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required [7]. In this research, active thermography was implemented.

Two type of heat sources were introduced which are water and steam. As to perform the hot water inspection, the pipe was pumped with 50°C and 60°C hot water while for steam inspection, the pipe was heated until the pipe external surface reach 70°C, 80°C and 90°C. Reaching the desired temperature, the heating process was stop and FLIR 640 IR camera as shown in Figure 2 will begin to capture the radiant emittance automatically at 7 seconds interval during cooling period. The emissivity value of carbon pipe was obtained according to ASTM E 1933 – 99a standard.

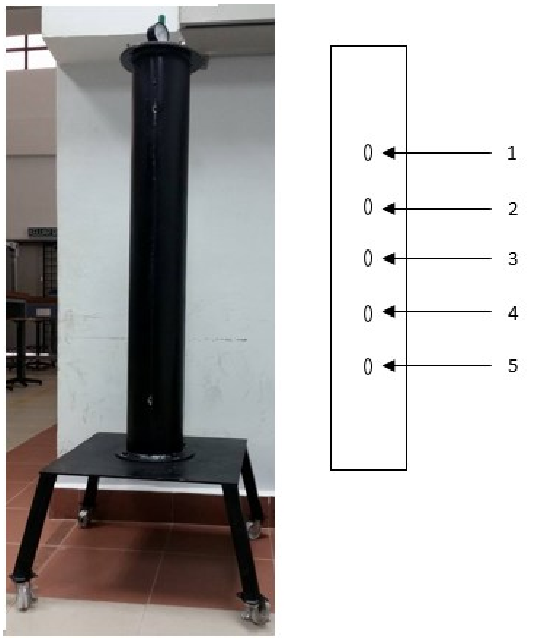

Fig. 1 Pipe with defect illustration

Table 1: Depth of shallow pitting

Spot	Dimension (mm)	Depth of pitting (mm)	Percentage of penetration (%)
1	15 x 30	1	10
2	15 x 30	2	20
3	15 x 30	4	40
4	15 x 30	6	60
5	15 x 30	8	80

Fig. 2 FLIR T-640

3. Results and Discussion

3.1 Water Heat Source

Figure 3 shows the thermal image within 168 seconds cooling period after exposed to 50°C of water. This is the optimum frame to locate maximum numbers of defects in a single Infrared (IR) image. Based on the heat transfer theory, thinner surface will cool down faster compare to thicker surfaces. A straight line was drawn next to the spot to compare the temperature difference. The defects spots have slightly lower temperature compare to the surrounding spots. The average temperature for the line is 42.7°C while the temperature of the spots ranges from 42.5°C to 42.7°C.

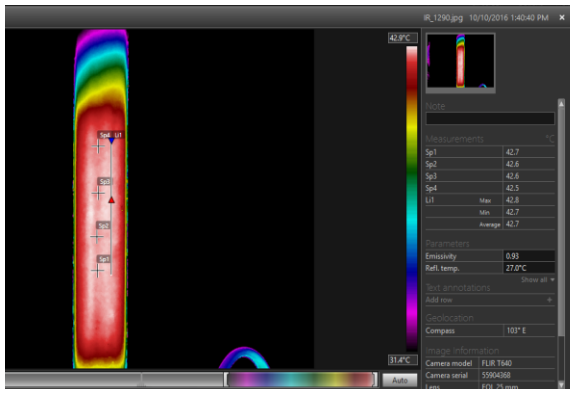

Fig. 3 Thermal image of 50°C hot water

Figure 4 shows the thermal image within 245 seconds cooling period after exposed to 60°C water. There are 3 spot of defects can be observed from the thermal image. A straight line is drawn next to the spot to compare the temperature difference. The defects spot have slightly lower temperature compare to the surrounding spots. The average temperature for the line is 50.2°C while the temperature of the spots ranges from 49.7°C to 50.1°C.

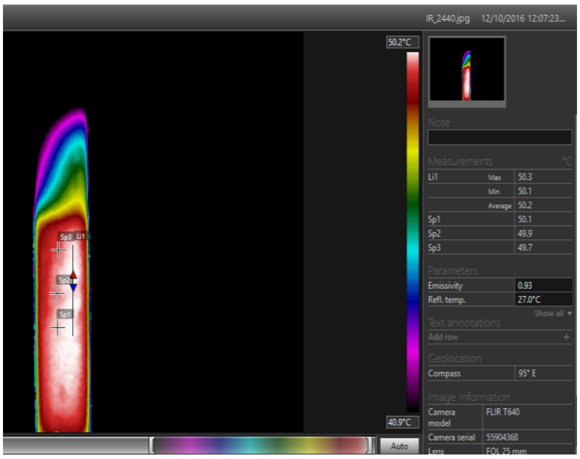

Fig. 4 Thermal image of 60°C hot water

3.2 Steam Heat Source

Figure 5 to Figure 8 conclude that the higher heat source been introduced, the less time it takes for the spot to appear in thermal image. These data are taken from 5 set of experiments for different heat exposure individually. Artificial defect with lowest pitted penetration named as Spot 1, shows no significant thermal gradient for all of the experiment except for 90°C steam exposure.

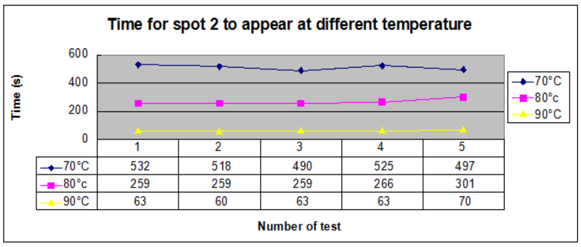

Figure 5: Spot 2 with 2 mm pitted

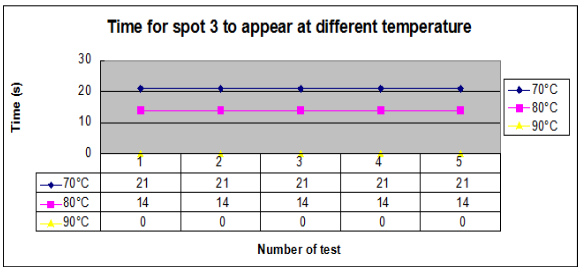

Fig. 6 Spot 3 with 4 mm pitted

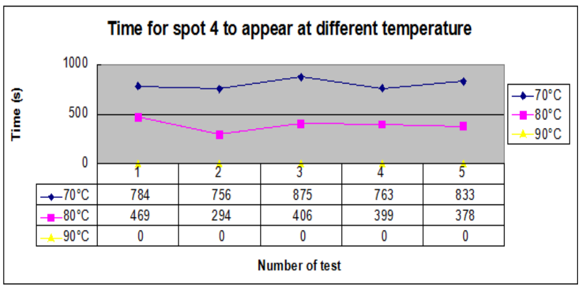

Fig. 7 Spot 4 with 6 mm pitted

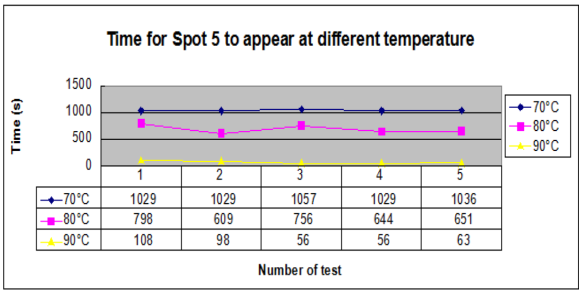

Fig. 8 Spot 5 with 8 mm pitted

Table 2 shows the tabulated data to show the average time for each spot to appear in thermal image. Comparing the three different temperature, temperature 90°C gives the shortest time for the spot to appear while temperature 70°C take the longest time. It shows that the higher heat source been introduced, the less time it takes for the spot to appear in thermal image.

Table 2 Average time appear

Spot	Average time appear (s)		
	70°C	80°C	90°C
2	512.4	268.8	63.8
3	21	14	0
4	802.2	389.2	0
5	1036	691.6	76.2

3.3 Comparing Cross Sectional Area

Figure 9 shows an artificial of wide and shallow pitting in the carbon steel pipe. The actual cross section area is 626.71 mm^2. Size ratio can be achieve by comparing both Thermal Image and Actual Image cross section area as to reveal another value added data.

Fig. 9 Artificial wide and shallow pitting in pipe

Figure 10 to Figure 12 shows the thermal image undergo Image analysis software. The defects area in the thermal image range from 915mm^2 to 1392mm^2. It means that the area of defect appear in thermal image are 146% to 222% larger than the actual size. Therefore, it can be conclude that the real cross sectional area of defect is actually smaller than the area of defect measured from thermal image.

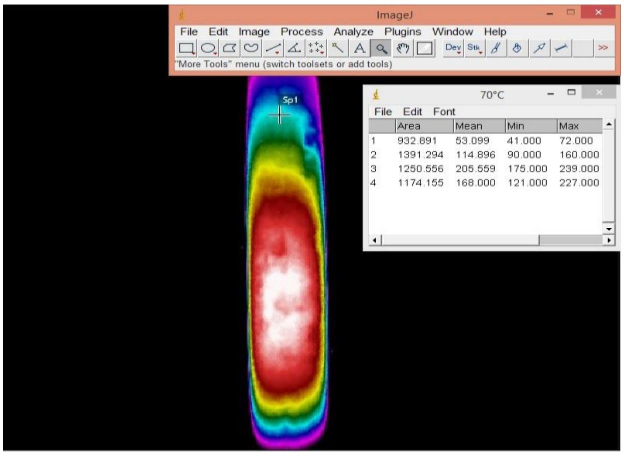

Fig. 10 Image analysis for 70°C steam exposure

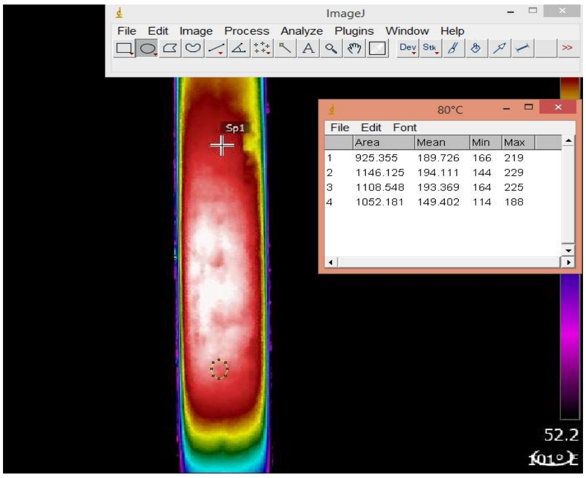

Fig. 11 Image analysis for 80°C steam exposure

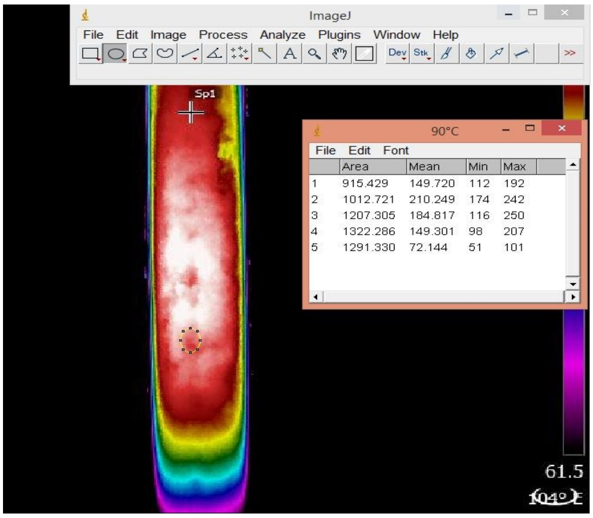

Fig. 12 Image analysis for 90°C steam exposure

4. Summary

As a summary, infrared thermography technique was introduced as a method to locate wide and shallow pitting in a carbon steel pipe where water and steam was used to heat up the internal surface of the pipe. From the experiment, these infrared thermography methods are able to detect the defects in the pipe. As heat source been expose within a different temperature range, FLIR T640 will captured different amount of radiance emittance result to difference thermal gradient in IR image. The cooling period begin after the surface temperature reaches certain desired temperature.

The results shows that Spot 5 with 80% of pitted penetration had a consistent IR image at any level of heat source been introduced. The others Spot with less percentage of penetration are yet available for future recommendations.

It also found that the defect cross sectional area in IR image appear larger compare to its actual size. The defect area ratio is 1.46 to 2.22 times bigger compare to its actual size. The research have a bright future since more knowledge can be study from infrared thermography and perhaps future related research will able to contribute more for the industry.

In a nutshell, infrared thermography is an effective condition monitoring tool which provides real time color coded image of the object and allows non-contact during inspection.

5. Acknowledgement

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