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PREDICTIVE MAINTENANCE USING THERMOGRAPHY TECHNIQUES FOR INSPECTION OF PIPES

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Abstract. *One of the biggest industrial challenges is operate safely, economically, reliably and with equipment with the highest availability possible for operation. One way to achieve these goals is using the predictive maintenance techniques, which are a set of programs for monitoring "on-line" machines and equipment to predict failure and prevent further damage. Infrared thermography is one of the main techniques used in predictive maintenance of equipment and, if properly used, becomes a useful tool to perform inspections, detect defects in its early stages and avoid unscheduled downtime. Temperature is a key variable in any process, and thermography consists of techniques or methods for determining a thermal profile graphically. This can be very useful in detecting anomalies that represent risks to the safety of employees or failures that will result in interruptions in production processes and, consequently, economic losses. This work aims to present the advantages of using infrared thermography in the prevention of mechanical failures in industrial units, exemplifying their applications in pipe inspections in mining company VALE S.A., in Vitória – ES.*

Keywords: *thermography, maintenance, predictive, pipe*

1. INTRODUCTION

The temperature is an essential variable for any situation and for any process. In the industrial sector, there are infinite examples where temperature is very important. In the casting process, for example, it is necessary to raise the temperature of the material until it burns out, and cast it in the desired format. This variable is so important that to have control over it means higher quality, better security and money saving.

Thermography consists, basically, in methods or techniques that allow report a thermal profile in graphical form and may be carried out by contact, coming from chemical reactions on the surface using ink, paper, liquid crystal and other special temperature-sensitive substances or without contact. The Infrared Thermography consists in the acquisition and analysis of thermal information from obtaining non-contact thermal imaging devices (ITC, 2008).

Thermography can be described as a non-destructive thermal test, used to obtain the surface temperature profile structures and subsequently the obtained correlation information with few internal imperfections (Willians *et al*., 1980). According to Giorleo *et al*., 2002, thermography is a non-destructive dimensional technique used to measure the surface temperature field of all types of materials.

Infrared Thermography has high quality using a remote sensor, then, does not need the contact to perform measurements. This can be very advantageous in situations where it is essential to keep you out of danger, as in applications in electrical maintenance. Another important condition for many applications is that Infrared Thermography does not interfere or affect the target, the cameras only exhibit radiation naturally emitted. The thermal image allows a great overview of the target. With only one image can be detected where potential problems are located, because thermography visualizes thermal patterns so that analysis can be made (ITC, 2008).

The use of thermography requires knowledge and ability to interpret and understand the generated thermal imaging. This technology extends to several areas of study, for example, the condition monitoring (electrical, construction, furnaces and boilers, mechanical, tanks, containers and fluid flow problems), research and product development, veterinary medicine (identify inflamed points, circulation problems, etc.), quality control and process monitoring (continuous temperature measurements).

Thermographic cameras, also known as Thermographs, are equipped with special detectors that turn readings of temperature fields in video images. Each temperature is designated a color or shade of gray, such that an image can observe the temperature differences between components (ITC, 2008).

Due to these features, thermography has been increasingly used for preventive and predictive maintenance in various segments such as, metallurgical, chemical, steel and others (Pelizzari *et al.*, 2006).

The maintenance is intended to restore or maintain the operational status of equipment in their normal conditions, providing their effective productivity and production quality. The main objective of a maintenance department is to maintain the equipment that is on their responsibility in working condition to supply the functions required of them (Mirshawka, 1991). Currently, the mission of maintenance is to ensure the reliability and availability of equipment and installations to supply a production process or service with safety, environmental protection and appropriate cost (Kardec and Nascif, 2005).

One of the important types of maintenance is the predictive, that consists in performing maintenance at an appropriate time before the machine to crash, and is intended to avoid functional failure or avoid the consequences of this, based on the analysis of the evolution parameters supervised significant deterioration of the component, allowing interventions plans (Moubray, 1997). Through predictive techniques, it is done the condition monitoring and corrective action, when necessary, is carried out in a planned corrective maintenance (Kardec and Nascif, 2005).

Predictive maintenance can mean a savings equal to 30 times the amount invested. It consists in anticipated the plan of corrective interventions from the systematic application of one or more monitoring techniques, such as analysis of rotary and alternative equipment vibration, current analysis and magnetic flux electric motors, lube oil analysis, thermography of electrical and mechanical systems, ultrasound for leak detection and discontinuities, etc. (Moubray, 1997).

This work aims to demonstrate the advantages and the growing tendency of using infrared thermography in mechanical failures preventing in the industrial sector, as shown in others studies (Monteiro *et al.*, 2013 and Araujo, 2014), exemplifying its use in the pipe inspections in the mining company VALE S.A. in Vitória - ES.

2. METHODOLOGY

2.1 History

In Vale S.A. the mapping of pipes was a large-scale problem. The techniques used most often spend time, needed skilled labor and an onerous cost to predictive maintenance area, and still did not avoid the faults. Research development demonstrated that the PEAD (high-density polyethylene) pipe was the most suitable material for transport coal slurry.

At first, it was used a visual inspection to identify the points of internal wear of the pipe, which caused a significant loss of time, because the actions only could be executed after the total wear of the surface, when happened the leak of material. The conclusion is that it was more appropriate to work preventively to have a more efficient control of pipe wear, and consequently improve its life, programming interventions with criterions adopted by the inspector.

By difficult access to most of the pipes, it was crucial to develop a predictive inspection technique that attended this restriction. The inspection team began intensive work to find on the market a predictive technique that could be used in the plant. The thermography was chosen and this technique was widely used with a focus on electrical inspection and could attend the inspection team from the pipes of Vale S.A. very satisfactorily.

To confirm the efficiency of the use of this inspection, it was executed this technique in a pipe where the wear was already known. The test was first carried out in a new section of pipe and its thermal image (Fig. 1) shows a uniform temperature profile. Two more tests were conducted in the same section of the pipe: (*i*) one after a little sanding in the pipe, as shown in Fig .2 a) – white zone in the middle of the section, and (*ii*) other after a severe sanding in a point where there was almost a leak, as shown in Fig. 2 b – white point in the lower zone.

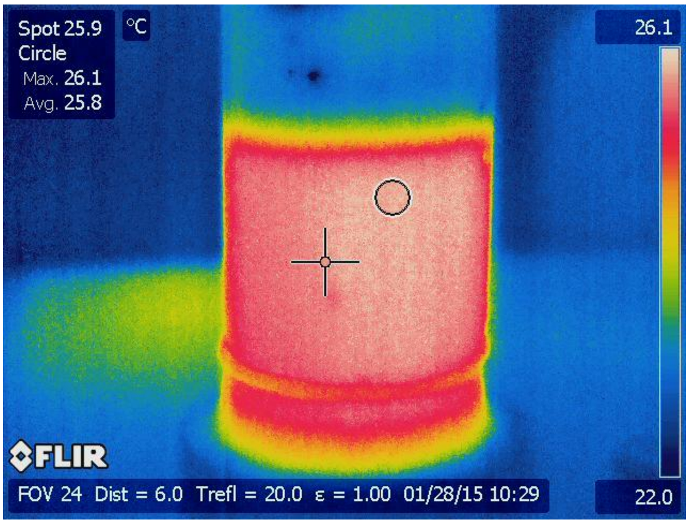

Figure 1. New pipe with water

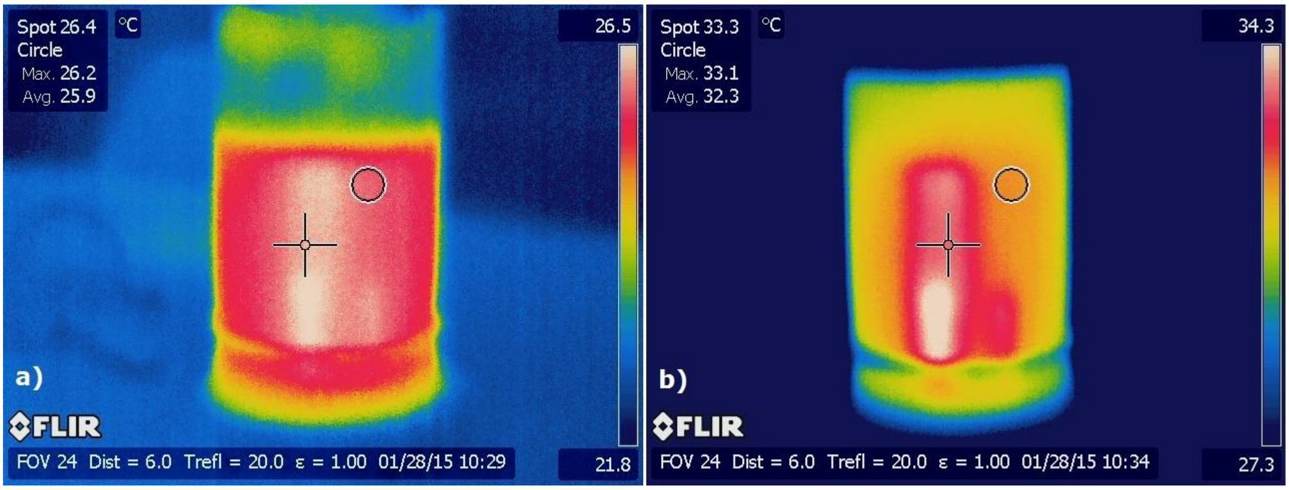

Figure 2. Pipe with water: a) little worn and b) almost leaked by wear

2.2 Thermographic Inspection

The inspection began to be developed from January 2015, due to defects that occur frequently in the pipe carrier coal slurry, thereby reducing the production of pelletizing plants. The inspection was executed with a thermography camera FLIR P640 (Fig. 3), handled by inspectors, and aimed to detect points along the entire pipe that are prone to failure, which concentrates more heat. The technique is still used as qualitative thermography, which depends on the analysis of the thermal patterns to reveal the existence and the position of abnormalities, with the important parameters of the apparent emissivity and temperature. This technique aims to identify the pipe's inner lining wear points before it reaches the outer surface and break them.

Figure 3. Thermographic Camera utilized: FLIR P640

Modern infrared cameras provide access to the measurement of thermal fields and their time evolution. Image processing obtained is used to analyze the thermal signature of moving objects or fluids flowing (Palma, 2009). Currently, the thermografers are portable, can be connected to computer and have software for image analysis, which simplify the applications.

All objects emit thermal radiation to the environment and the magnitude of the radiation varies with wavelength (Bergman *et al.*, 2011). Although the electromagnetic waves have the same general characteristics, different wavelengths differ significantly in their behavior (Çengel and Ghajar, 2012). The camera captures an image of the radiation emitted from the surface of most objects. The surface temperature is directly related to the type of object, the material this is made, the components and operation of the components inside these objects. For the purposes of thermal imaging is essential to know the materials involved and the operation of the equipment analyzed.

Figure 4 shows the generated thermal image that allows identify that the pipe (right side) is carrying coal slurry at the time of image capture, due to higher temperature compared to the disabled pipe (left side).

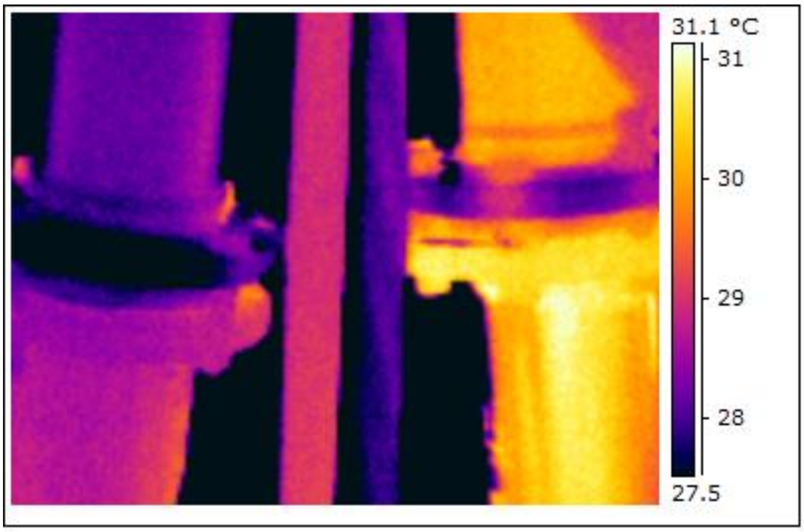

Figure 4. Thermal pipe image

The precision of an infrared camera depends on many components, such as lenses, filters, detector reading circuit and signal processing and linearization and compensation programs. It is a device widely used in the industrial sector, which identifies the infrared waves turning into visible images to the human eye. The capture of the thermographic image is made by freezing and storing. To draw up a report, the image should be stored in the camera and later transferred to the computer.

There are three things that can never be changed after freeze and save the image, which is the temperature range, the optical focus and the picture composition. Before performing image capture, the operator, such as showed in Fig. 5, should check that these factors are correct, otherwise the results will be unsatisfactory and the inspector must return to the area to capture new images (ITC, 2008).

Figure 5. Inspector using the Thermographic Camera

2.3 Cares in Thermographs Manipulation

Care should be taken in predictive inspection in order to avoid a false diagnosis in some equipment, because there are factors that can mask the resulting image and undermine the conclusion in relation to it.

The reflection, showed in Fig. 6, is a problem that can change the diagnosis given to any equipment as it can portray something unreal in the thermal image. Some precautions can avoid this problem, like not capture the image directly in front of the target to avoid reflect yourself, move from side to side to see if the point in the image also moves, and detect thermal gradients in the image, because the reflexes generally do not exhibit the same (ITC, 2008).

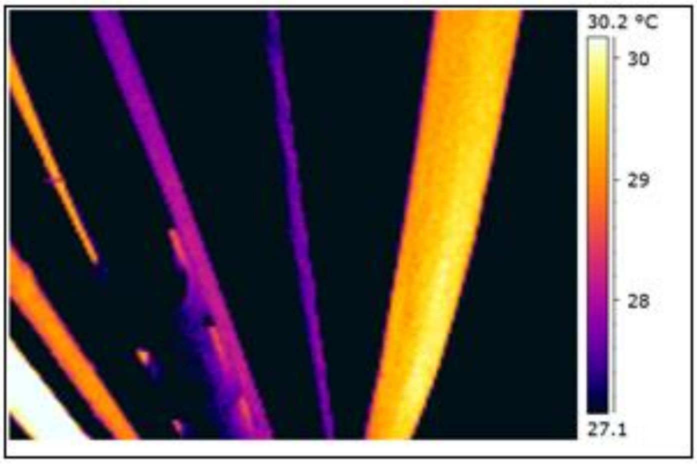

Figure 6. Radiation interference in the thermal image

Another case that can mask the result of thermographic test is the effect of external factors on the system under study, such as leaking oil, water, or any other unusual substance to the environment studied. In Fig. 7, it is possible to observe the unexpected effect that can cause a leak in a thermographic inspection.

In the studied section, the inspectors did not realize the leakage and made the capture of the image. The result scared everyone, due to a huge temperature variation in a region where it was not expected some wear because the area was affected by an external factor. There was a leak in the junction between the straight section and the pipe bend, which wet the outer wall and change, significantly, the thermal image.

Figure 7. Interference of a leak in the thermal image

Another external factor that can change the diagnosis in a thermographic inspection is the dust that is impregnated in the outer wall of the pipe, as can be seen in Fig. 8a).

The thermal image generated, Fig. 8b), is a result of an inspection where an unexpected temperature variation was identified in a straight section of the duct. When the inspectors analyzed the pipe, they identified the existence of a lot of dust on the surface of it.

The graph showed in Fig. 8c) helps to see the magnitude of the temperature variation and shows what a simple dust is able to generate at the thermal image. The variation founded was 2.5ºC in the studied section.

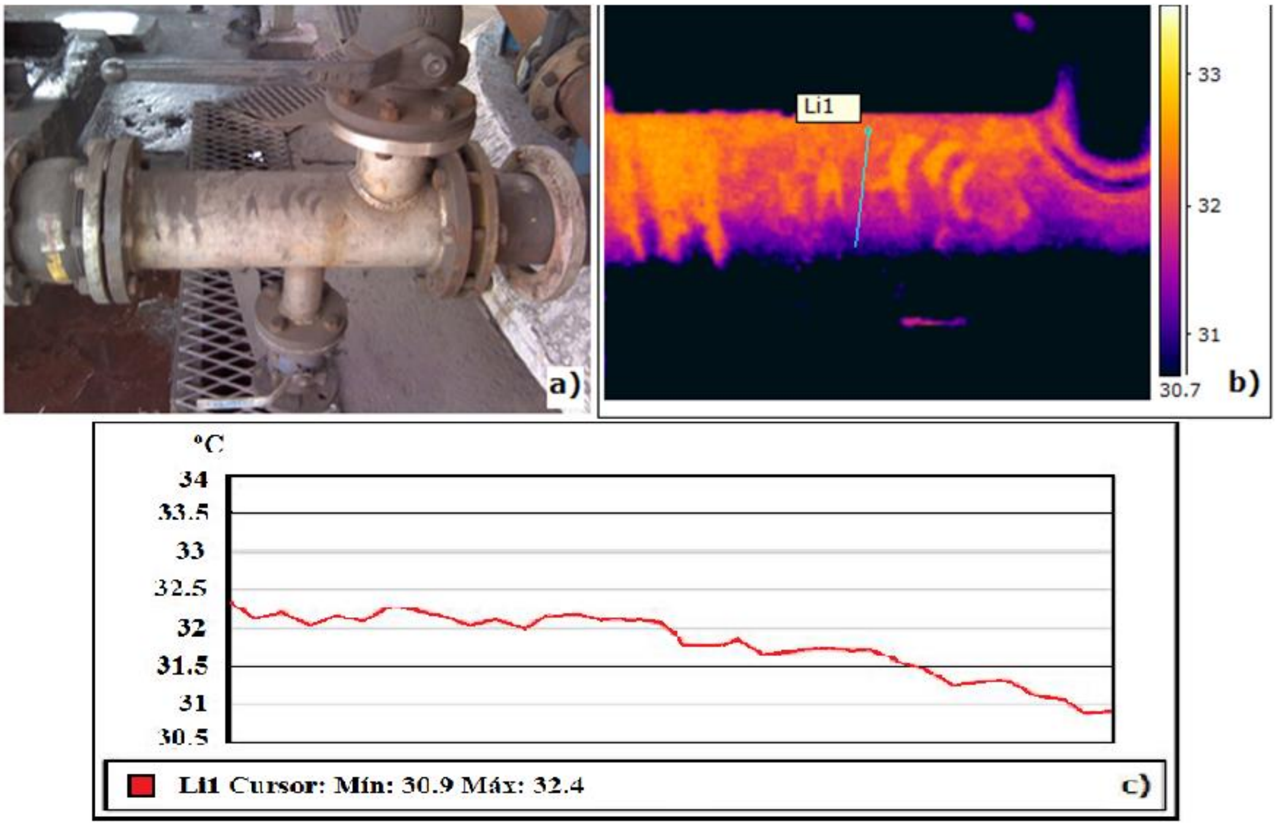

Figure 8. Dust interference: a) in real plant, b) thermal image and c) temperature variation at line 1 (Li 1)

3. RESULTS

The planning of actions was initiated by identifying points of intervention. After completion of thermography in the pipes of the plant, it was found that some places had abnormal temperatures. These examples were initial measurements that detected the existence of a problem, due to temperature excess. The fact that the Thermographic images are obtained in real time allows to make very fast scans, and with it, many dangerous situations can be discovered earlier, favoring a more effective corrective action.

Images captured at the stage of the Thermographic inspection procedure tests shows the pipes carriers coal slurry of Vale S.A. and their respective thermal images. In Fig. 9 and 10 there are points where the temperature is higher than the expected, which implies that the thickness of the pipe wall is smaller, and actions must be taken to avoid the unexpected disruption of the pipe.

The cause of this wear is due to the friction generated by the contact of coal slurry with the inner wall of the pipe, which generates the heat perceived by the Thermographic camera.

Figure 9. Pipe carrier coal slurry and your corresponding thermal image

In Fig. 9, there is a straight section of pipe carrier coal slurry where the inspectors suspected wear and decided to hold a Thermographic inspection to see if the suspect was true. Equipped with a FLIR P640 camera, the inspector captured a thermal image of the pipe under study and identified a temperature variation in the bottom of the pipe, which occurs due to wear in the inner wall of the duct.

This wear occurred in the lower region, due to the action of gravity on the coal, pressing it against the lower region of the duct. The thermal image shows this variation of temperature.

Figure 10 shows that there is wear on the inner lining of the duct and a considerable variation in temperature in the center of the intersection "T", which proves the existence of the wear, generated by the friction of this coal slurry with the pipe wall.

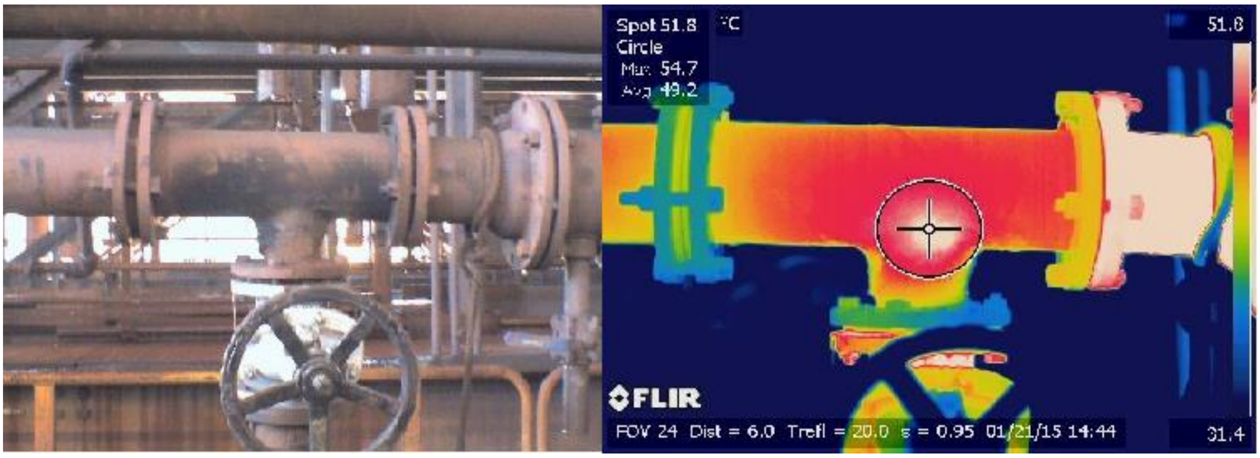

Figure 10. Articulation in the pipe carrier coal slurry and your corresponding thermal image

In the example showed in Fig. 11, temperature variations has been identified in the region of the junction between two ducts, which as in previous examples, representing a wear in the connection studied.

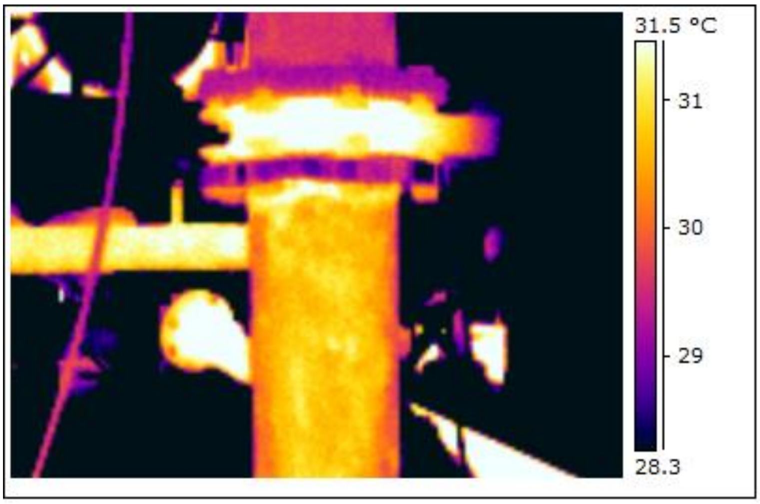

Figure 11. Thermal image of the pipe junction

When plant activities were interrupted for scheduled maintenance shutdown, the thermographic inspection process detected key points in equipment that show potential failures, proving the effectiveness of the tool.

After the proposed interventions, it was carried out new thermographic inspection in points with abnormal temperature and concluded that interventions emerged effectively, resulting in attenuation levels of temperatures of the points mentioned above, because this is pipes with uniform fluid passage and the temperatures of all pipe must be very close. Thus, hot spots were eliminated, equipment were released for operation and was determined by the engineering industry performing the thermographic inspection at all pipes carriers coal slurry plant.

4. CONCLUSION

To meet a request from maintenance team, the consistency of the thermographic analysis was evaluated by applying them for pipe inspections in a mining company. Before start using this tool to help the inspection team to identify possible problems, some test was performed to confirm that thermography is able to identify this points by its thermal profile.

The resulted presented in this work showed that this technique, widely used in the maintenance of electrical components, can also be very useful in mechanical maintenance. When applied in pipe inspections can be quite helpful advising critical points (excess of temperature) susceptible to failure, and avoid equipment and personal damage and also economic losses.

Among the numerous advantages of thermography techniques, some of them are essential in this kind of inspections: (*i*) does not need the contact to perform measurements, (*ii*) does not interfere or affect the target and (*iii*) images are obtained in real time. Therefore, it allows making quick and efficient predictive actions.

Despite the apparent simplicity, cares should be taken in handling the thermal camera to not invalidate the results. Small details such as dust in the measured surface or a liquid leak on it can interfere in the results. Furthermore, the reflection should also be avoided.

Anyway, if correctly used, technique of thermography becomes an important first analysis tool of failure indicating critical points in the mechanical maintenance routine. However, after this analysis it's usual to do a more accurate analysis, such as ultrasound.

5. ACKNOWLEDGEMENTS

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