International Journal of Engineering Materials and Manufacture (2023) 8(4) 88-94
https://doi.org/10.26776/ijemm.08.04.2023.01

Effect of Temperature on Penetration of Test Liquid into Boiler Pipe

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Received: 11 September 2023
Accepted: 12 October 2023
Published: 20 October 2023
Publisher: Deer Hill Publications

ABSTRACT
Limitations of time in conducting superheater inspections during overhaul, allowing inspectors to conduct liquid penetrant testing activities above pre-determined temperatures. This results in results obtained from the superheater inspection tube boiler indicating a false defect. This study aims to determine the optimal temperature and the impact of testing above the temperature that has been determined in ASME boiler and pressure vessel code using liquid penetrant testing method. This study uses 3 different penetrant brands and test specimens in the form of a superheater tube boiler. Spraying of penetrant fluid is carried out at normal temperature of 30–52°C and above normal temperature is 53–65 °C. The best crack and easy to read image results are tested at 40 °C A, B and C. For testing at temperature 53–65 °C crack thickness level is not clear and hard to read.
Keywords: Aluminium, Surface oxidation, preheat temperature, central composite design.

1 INTRODUCTION

Liquid penetrant testing is a type of NDT (Non-Destructive Test) testing method that is relatively easy and practical to carry out. This liquid penetrant test can be used to determine discontinuities on surfaces such as cracks and porosity. In principle, the test method with liquid penetrant utilizes capillarity [1]. In this method, liquid penetrant is applied to the surface of the specimen at a certain time that has been determined, after a while the penetrant on the surface is cleaned before developer is applied to reveal the liquid penetrant remaining in the crack, so that the developer will draw the liquid penetrant to the surface and the defects will be visible [2].

Time constraints in carrying out superheater inspections during overhauls make inspectors carry out liquid penetrant testing activities above a predetermined temperature. This affects the image results which do not match the actual indication of defects. So, this research was carried out to determine the effect of temperature on the results of the penetrant test on the boiler tube superheater. Where the superheater tube boiler test will be carried out at a temperature of 30 °C – 52 °C (normal) to find the best temperature using the liquid penetrant testing method and at a temperature of 53 °C – 65 °C (above normal temperature) to find out how big the deviation is. because it is carried out outside the specified temperature. One way to find out the best results of penetrant testing is to compare it with the results of radiographic tests. In the future, it is hoped that the results of this research can be used by boiler experts/boiler inspectors as a reference for penetrant testing in superheater tube boilers.

Boilers. A boiler is a pressure vessel used to heat water or produce steam to provide heating facilities in industry and produce electricity through a steam turbine drive [3]
Superheaters. Basically, a superheater is a convection unit whose purpose is to increase the temperature of saturated steam without increasing its pressure. Usually, this device is an integral part of the boiler, and is placed in the hot flue gas line from the kitchen [4].

Non-Destructive Tests. Non-destructive testing or what is better known as NDT "Non-Destructive Test" is a way to test the quality or condition of an object, item or product without damaging the object [1].
Liquid Penetrant Testing. This liquid penetrant testing method is effective for detecting open discontinuities in non-porous metal and non-metal materials.
ASME standard. Based on the ASME Boiler and pressure vessel code for carrying out liquid penetrant testing, the permitted temperature is from 10–52 °C [5].

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Reference: Abidin et al. (2023). Effect of Temperature on Penetration of Test Liquid into Boiler Pipe. *International Journal of Engineering Materials and Manufacture*, 8(4), 88-94.

2 EXPERIMENTAL DETAILS

2.1 Time and Location of Research

This research was carried out at the Workshop Laboratory of the College of Nuclear Technology-BATAN, Yogyakarta. The implementation time is 4 (four) months starting from April 2018 to July 2018. The procedure followed in this research are presented in Figure 1.

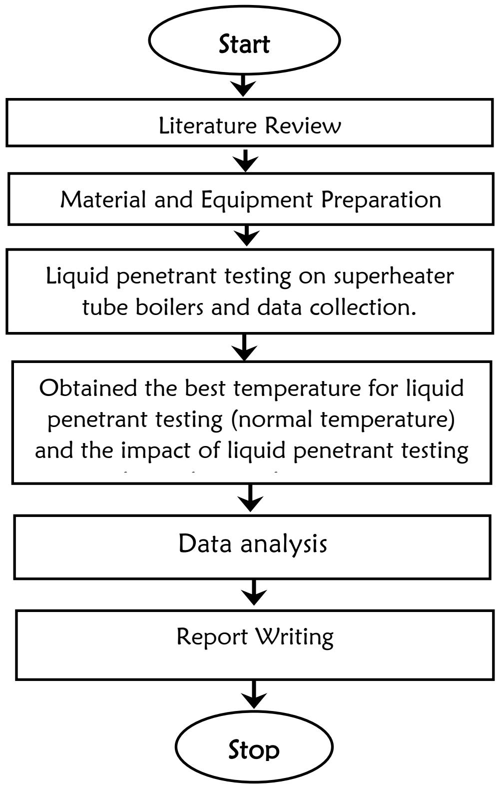


Figure 1. Flow chart of research activities

2.2 Preparation of Materials and Tools

Prepare materials and tools to be used for penetrant testing with the steps shown in Figure 2. The superheater tube boiler is cleaned of adhering dirt and cut into lengths of 27 cm from the initial length of 6 m. This material is then subjected to radiographic tests to see the initial defects on the surface. When there are no defects on the results of the first radiographic test, cracks are then made using laser cutting. After the manufacture of defects is complete, then a tube cover is made which functions to keep the heat maintained inside the tube and the temperature does not easily drop quickly. When the tube cover and crack are finished, a second radiographic test is then carried out which is useful to see the length and shape of the defects made as shown in Figure 3.

When the results of the second radiography can be read clearly then proceed with the manufacture of a heating device, this tool functions to raise the surface temperature of the tube when testing liquid penetrant. The next step is to make a photo studio box with a length of 30 cm, a width of 20 cm and a height of 20 cm which functions to take pictures of the results of the penetrant test.

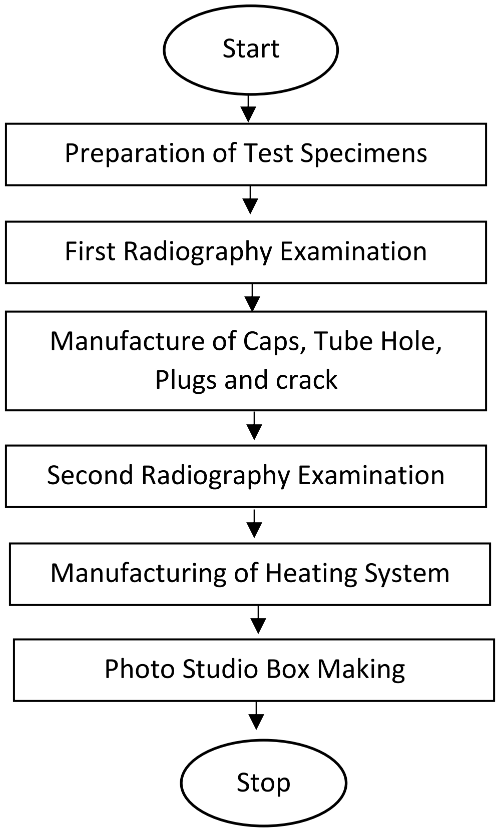


Figure 2: Flow chart for the manufacture of materials and test equipment

Figure 3: Defect Length of Radiographic Test Results

2.3 Liquid Penetrant Testing on Superheater Tube Boilers and Data Collection

Liquid penetrant testing on the boiler tube superheater starts from a temperature of 30–52 °C according to ASME standards (Table 1), the second material is tested at a temperature of 53–65 °C outside the ASME standard. This method is applied to penetrant brands A, B and C. The following are the test steps.

1. Knowing the surface temperature of the test object.
2. Liquid penetrant coating.
3. Penetration waiting time shown in Table 1.
4. Cleaning the remaining penetrant liquid on the surface of the test material.
5. Drying after cleaning the penetrant liquid.
6. Developer coating.
7. Evaluation / Interpretation.
8. Final Cleanup.

After testing the liquid penetrant on the superheater tube at normal temperatures from 30 °C – 52 °C until the best temperature is obtained. Parameters that the best temperature has been obtained, can be seen from the defect image which is clearly visible compared to testing at other temperatures. For abnormal testing, it is carried out from a temperature of 53 °C – 65 °C, when the test results are obtained, data analysis is immediately carried out.

Table 1 Penetrant waiting time (ASME, 2010)

Material	Form	Type of Discontinuity	Dwell times (minutes) (at 10° C-52° C)	
			Penetrant	Developer
Aluminium, magnesium, steel, brass and bronze, titanium, and high temperature alloy	Casting and welds	Cold shuts, porosity, lack of fusion, cracks (all forms)	5	10
	Wrought materials- extrusions, forgings, plate	Laps, cracks (all forms)	10	10
Carbide-tipped tools		Lack of fusion porosity, cracks	5	10
Plastic	All forms	Cracks	5	10
Glass	All forms	Cracks	5	10
Ceramic	All forms	Cracks	5	10

Table 2: Superheater Tube Specifications

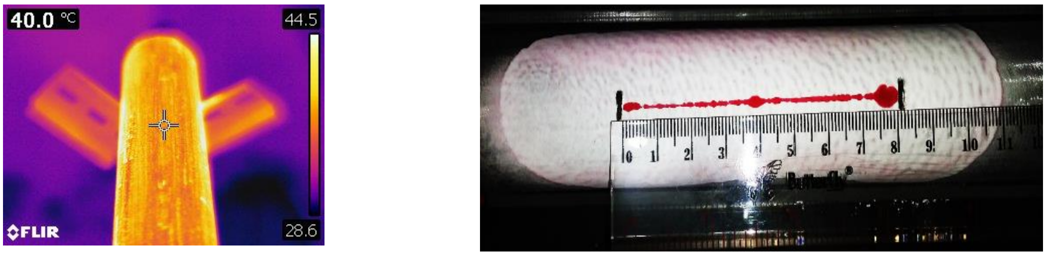
Product	DIN 17175 seamless alloy steel tube
Standard	DIN 17175
Material	15Mo3
Chemical composition (nominal) 96	C=0.16; Si=0.3; Mn=0.6; Cr <0.20; S=<0.035; P=<0.035; Mo=0.3
Outside diameter	38 mm
Inside diameter	31 mm
Length	6 mm
Heat input at MRC case 1	7.36 x 106 Kcal/hr
Inlet steam temperature at st MR case 1	420/490 °C
Tube design temperature	550°C

2.4 Data Analysis
Knowing the best temperature for carrying out liquid penetrant tests and knowing the impact of tests carried out outside the temperature set at ASME. The test results are seen from the thickness and length of the defect due to the influence of heat on the test object which is then compared with the radiographic test results.

3 RESULTS AND DISCUSSIONS
This research uses a superheater tube boiler test object because the heat received is the highest compared to other boiler components, namely 420/490 °C which is shown in Table 2 along with its specifications. High temperatures inside and outside the tube result in frequent damage in the form of bulging (bulging) and tube rupture with the initial indication being cracks on the surface of the material [6]. For this reason, a non-destructive test was carried out using the liquid penetrant testing method, which is useful for knowing indications of initial defects on the surface of the tube. The earlier you know there is an indication of a defect, the more prevention can be done before an unwanted incident occurs. Therefore, penetrant testing is carried out as the initial step of the examination. So that the inspection carried out produces an image that reflects the actual defect, this research was carried out with the title The Effect of Temperature on the Results of Liquid Penetrant Testing on Superheater Tube Boilers.

Based on the ASME boiler and pressure vessel code for conducting liquid penetrant testing, the permitted temperature is from 10 °C – 52 °C [5]. The normal temperatures applied in this test start from 30 °C, 35 °C, 40 °C, 45 °C, 50 °C, 51 °C and 52 °C and temperatures above the ASME standard start from 53 °C, 54 °C, 55 °C, 60 °C, 65 °C. After testing, the resulting defect images vary based on the temperature on the surface of the test object when the penetrant liquid is sprayed. To be more specific, there will be 2 (two) points of discussion that will be explained, namely the thickness of surface defects and the length of surface defects due to the influence of temperature resulting from liquid penetrant testing.

3.1 Results and Discussion Based on Defect Thickness
3.1.1 Brand A
Tests carried out at a surface temperature of 40°C produced an image as in Figure 4a. This picture shows the temperature measured on the surface of the material, namely 40.0 °C with a range of 28.6°C – 44.5°C. The test results at this temperature are shown by a red line with the same thickness as the previous test. However, in the test at a temperature of 40 °C, 3 (three) thick dots appeared on the surface on the right, middle and left. This shows that the results of penetrant testing at a temperature of 40 °C are in accordance with the results of radiographic testing as in Figure 4b. This situation occurs because the surface heat of the material is getting higher. And it is indicated that evaporation has not occurred in the penetrant liquid when it is sprayed onto the material.



a b

Figure 4: (a) Material Image Result of Camera Flir (b) Defects that are produced at a temperature of 40° C

Then the last test was carried out at 65 °C as shown in Figure 5a. The flir camera image at the spot point shows a temperature of 65.1 °C and a range of 28.2° C –73.0 °C. Almost the same as testing at a temperature of 50 °C to 60 °C, namely the penetrant liquid evaporates. But at a temperature of 65.1 °C, the evaporation is higher, which is marked by the amount of smoke produced. Likewise, when the developer liquid is sprayed onto the surface of the test material, this liquid dries immediately and briefly lifts the penetrant. All of this results in the output that is a thin red line and a single dot to the right of the image. When compared with the results of radiographic images of these defects do not identify actual defects.

3.1.2 Brand B

When the test was carried out at a surface temperature of 40 °C it produced an image as in Figure 6a. This image shows the temperature measured on the material surface of 40.1 °C with a range of 27.7–44.5 °C. The temperature test results are shown with a red line which is thicker than the previous test. However, in the test at a temperature of 40 °C, 3 (three) thick dots appeared on the surface on the right, middle and left with a straight red line slightly interrupted on the left as in Figure 6b. This shows that the results of penetrant testing at a temperature of 40.1 °C are in accordance with the results of radiographic testing. It is indicated that evaporation has not occurred in the penetrant liquid when it is sprayed onto the material.

The final test on brand B was carried out at a surface temperature of 65 °C as in Figure 7a. The image produced by the FLIR camera at the point shows a temperature of 65.2 °C with a range of 30.2–72.1 °C. At a temperature of 65.2 °C, there was a very drastic decrease in thickness, even the red straight line in the previous test was still visible, in this test it was no longer visible. There is only 1 (one) thick dot on the right side of the image which is not too bright in color. The problem is the same as testing starting from a temperature of 50 °C, namely heat, the penetrant liquid evaporates, and the developer dries too quickly.

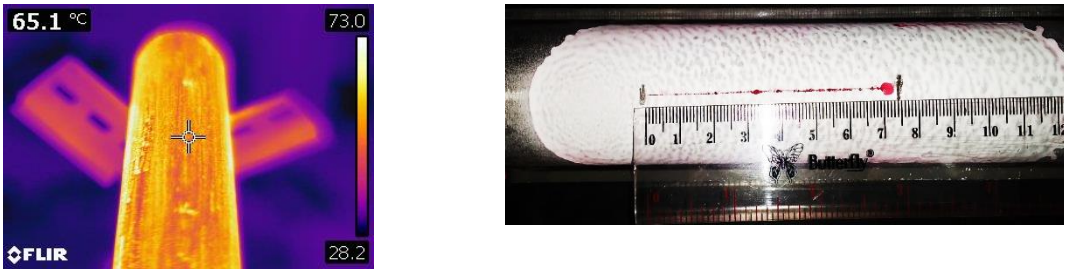


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Figure 5: (a) Material image from the Flir camera (b) Defects produced at a surface temperature of 65.1 °C.

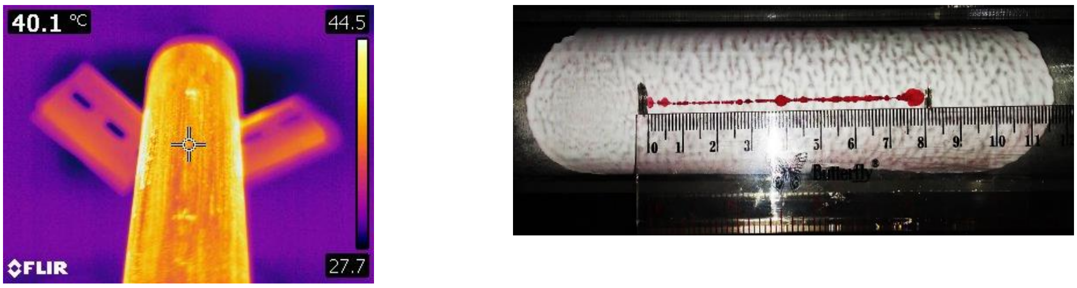

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Figure 6: (a) Material image from the Flir camera (b) Defects produced at a surface temperature of 40.1 °C

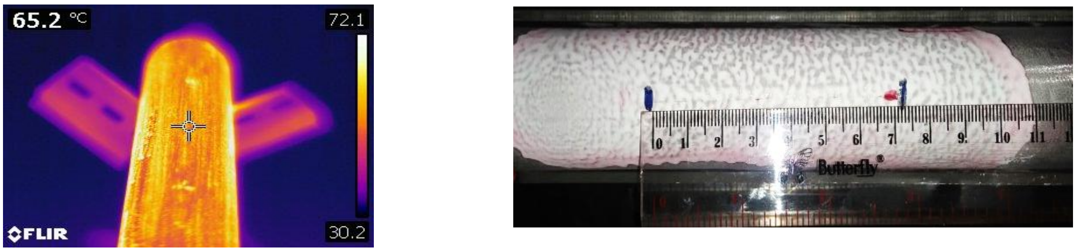

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Figure 7: (a) Material image from the Flir camera (b) Defects produced at a surface temperature of 65.2 °C

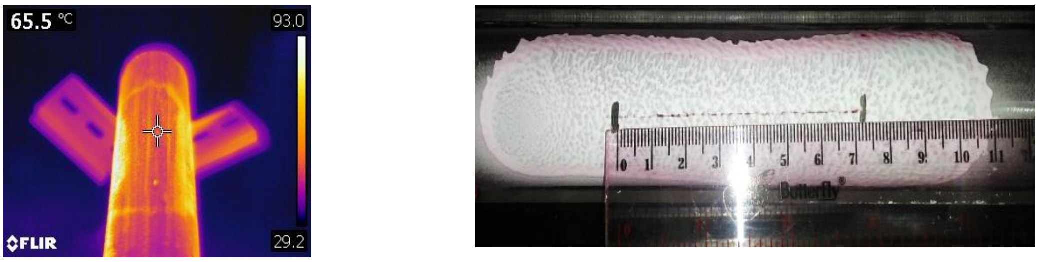
3.1.3 Brand C

Testing a surface temperature of 40 °C produces an image as in Figure 8a. This image shows the temperature measured on the surface of the material at 40.5 oC with a range of 30.9 °C – 51.2 °C. The test results at temperature are indicated by a thicker red line than the previous test which can be seen in Figure 8b. However, during the test at 40.5 °C, two thick dots appeared on the right and centre with a straight red line, slightly interrupted on the left. This shows that the results of penetrant testing at a temperature of 40.5 °C do not match the results of radiographic testing. This is because the surface of the material is not too hot, it is indicated that evaporation has not occurred in the penetrant liquid when it is sprayed onto the material.

The last test on brand C was carried out at a surface temperature of 65 oC as shown in Figure 9a. The image produced by the flir camera at the spot point shows a temperature of 65.5 °C with a range of 29.2 °C – 93.0 °C. At 65.5 °C, there is a very drastic decrease in thickness marked with a thin and interrupted red line. The problem is the same as testing at 50 °C, which is high heat, the penetrant liquid evaporates and the developer dries too quickly.

a b

Figure 8: (a) Material Image from a Flir Camera (b) Defects Produced at a Surface Temperature of 40.5 °C



a b

Figure 9: (a) Material image from the Flir camera (b) Defects produced at a surface temperature of 65.5 °C

3.2 Results and Discussion Based on the Length of the Defect

The radiographic test results show an 8.1 cm long defect image shown in Figure 4.13 which is marked with a green line. The length of this defect is the reference for determining the image of the defect produced in the liquid penetrant test. Defective images resulting from the penetrant test are said to be good if they approach the length of the defects resulting from the radiographic test. Based on Figure 10, it can be seen from the test results that the best liquid penetrant is brand A with all temperatures applied producing a length close to the length of the radiographic test results.

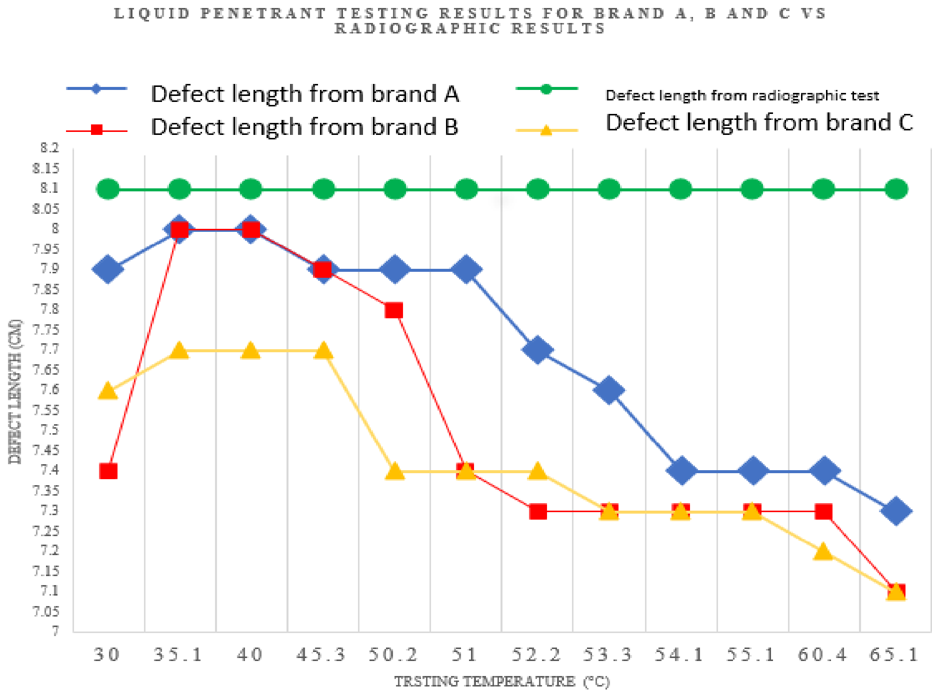


Figure 10: Graph comparison of liquid penetrant test results for brands A, B and C with radiography results

5 CONCLUSIONS

Based on research analysis of the effect of temperature on the results of liquid penetrant testing on boiler tube superheaters, it can be concluded:

1. The best temperature has been obtained for testing superheater tube boilers using the NDT (liquid penetrant testing) method brands A, B and C, namely at 40 oC, with the thickness and length of the penetrant that appears to the surface according to the actual defect and close to the image of the radiographic test results.
2. The results of liquid penetrant tests for brands A, B and C above 52 oC have a thickness and length that do not match the original defects, so they should not be done because they could indicate fake defects.

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