Available online at:
Al-Fiziya: Journal of Materials Science, Geophysics,
Instrumentation and Theoretical Physics
Website: http://journal.uinjkt.ac.id/index.php/al-fiziya
Vol.8 No. I 2025, 1-11

DAMAGE ANALYSIS OF INSULATED PIPES USING DIGITAL DETECTOR ARRAY AND COMPUTED RADIOGRAPHY

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Submitted: May; Revised: June; Approved: July; Available Online: July.

Abstract: The provision of insulation on the pipe functions to prevent heat transfer, but the provision of this insulation causes the pipe to be susceptible to damage due to oxidation. In this study, an analysis of damage to insulated pipes will be carried out using a Digital Detector Array (DDA), Computed Radiography (CR), and XRF. Based on the test results, it is known that the image quality using DDA with a voltage of 240 kV produces the most optimal contrast resolution. The results of the thickness dimension measurement using the DDA method on insulated pipes are 3.38 mm, and on insulated pipes with artificial defects are 4 mm. Compared with the CR method, the values are 3.02 mm and 3.94 mm, respectively. The smaller the difference, the more accurate. From the calculation of the ISee software, it is also known that the DDA method can detect a greater number of defects, namely 24, compared to the CR method, which has only 14. The results of the XRF test show that the insulated pipe includes low-carbon steel with a carbon content of 0.057% and 94% ferrum. This high ferrous content contributes to increased X-ray absorption, greatly affecting the images quality.

Keywords: Insulated pipe, Digital Detector Array, Computed Radiography, X-Ray Fluorescence.
DOI : 10.15408/fiziya.v8i1.46385

INTRODUCTION

A pipe is a tube-shaped channel that drains substances like gases or liquids. One application that requires strong pipes is their use as high-pressure conduits, such as oil and gas pipelines [1]. This pipe is made of low-carbon steel, which has good mechanical properties so that it can withstand high pressure and heavy workloads. The low carbon content in this type of steel also positively impacts rust and corrosion attacks [1].

High-pressure pipes are generally coated with insulators that keep the fluid's temperature stable and prevent heat loss. However, if the insulator is not installed properly, it can cause damage to the pipe due to water or moisture trapped between the insulator and the metal surface [2]. This condition creates a humid and corrosive environment. Based on data from SKK Migas's deputy for operations, there have been at least 2 leaks on Pertamina's pipelines in Karawang on April 15, 2021, due to the age of the pipes being old and corroded [3]. Corrosion on this pipe is not only on the outer surface but also under the insulator layer. This makes it difficult to detect damage experienced by pipes coated with insulators.

In this study, the damage that occurs in insulated pipes will be analyzed using the Digital Detector Array (DDA), Computed Radiography (CR), and XRF methods to determine the content of the elements. The results obtained are then compared with those of other insulated pipes that have been given artificial defects that resemble real damage so that a more effective digital Radiography method can be determined.

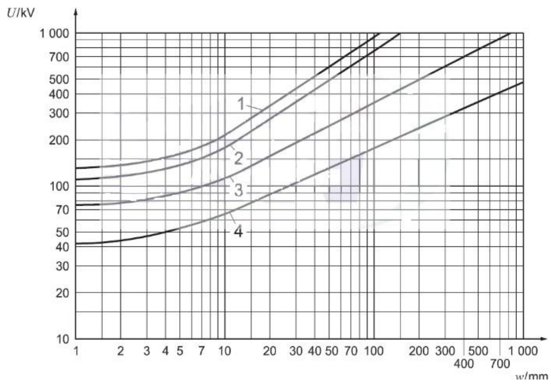
METHODS

The process begins with preparing the workpiece by making artificial defects on carbon steel pipes with a lathe process to make notches welding to make precipitation, and milling to smooth the surface. Shooting artificial defect pipes uses digital radiography, namely, a digital detector array and computed radiography. Based on ISO 20769-1: 2018, The radiographic technique used in this study is tangential with the radiation source located at the center line of the pipe. Setting the voltage starts with regulating the voltage and regulating the electric current, DDA and CR setting time. The distance between the sources to the detector/IP is 880mm. Shooting insulated pipes by installing DDA on top of insulated pipes is parallel to the emitted radiation source, with a distance between the sources and the detector of 590mm. The DDA shooting was carried out using 60kV to 300kV and 140 frames, while CR used IP with a shooting process time of 40 seconds and 180kV. The testing process uses XRF; the pipe sample is cut with a size of 4x6 cm into a plate shape; then, the sample was shot using X-rays to display the composition in detail.

RESULTS AND DISCUSSION

A. Image Quality

Radiography Test is a technique to obtain a shadow image of a solid object using the penetration power of X-ray radiation or gamma rays (γ). The image obtained is a projection of the object without details of its depth [4]. To get accurate images at tangential locations, the radiation energy must be higher than that used for double-wall inspection of the same pipe [5]. The implementation of digital radiography to determine the voltage (kV) used is based on the material and thickness of the object. In ISO-17636.2, there is an exposure chart in Figure 1, which is given for steel, aluminum, titanium, and copper, so for this experiment, stainless steel materials are used, which have mechanical properties identical to carbon steel by measuring the dimensions of the pipe consisting of the outer diameter and inner diameter as well as the thickness of the wall. These parameters can determine the Energy (KV) used [6]. One of the important parameters in the implementation of radiographic testing is the accurate irradiation time because it will determine the gray value. Errors or inaccuracies in determining the irradiation time can damage the resulting images and do not meet the quality standards of radiographic image reception [7]. Furthermore, calculating the distance from the source to the detector, the minimum source-to-detector distance (SDD) for artificial defect pipes was calculated at 294.8 mm. The object's distance to the detector (PDD) for artificial defect pipes is 36.85 mm. While the result of calculating the minimum source-to-detector distance (SDD) for insulated pipes is 308.8 mm. The object-to-detector (PDD) distance for insulated pipes is 38.6 mm.



Information:

U X-ray tube voltage

w translucent thickness

1. Copper and nickel and their alloys
2. Steel
3. Titanium and its alloys
4. Aluminum and its alloys

Figure 1. Grafik Exposure Chart

This study needs good image quality to detect artificial defects in pipes. The digital data of the radiographic detector should be evaluated with a linearized gray-value representation, which is directly proportional to the radiation dose for the determination of SNR, SRb, and SNRN. For optimal image display, contrast and brightness should be set interactively. Optional filter functions, profile plots, SNR, and SNRN tools should be integrated into the software for image display and evaluation [6]. In this Test, it is necessary to search for kV optimization to find the appropriate gray value, SNR, and SNRN. The results of the image can be seen in Figure 2.

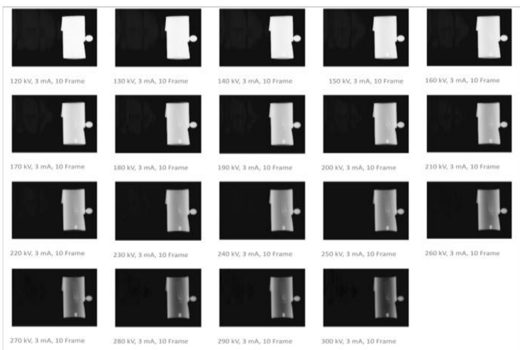
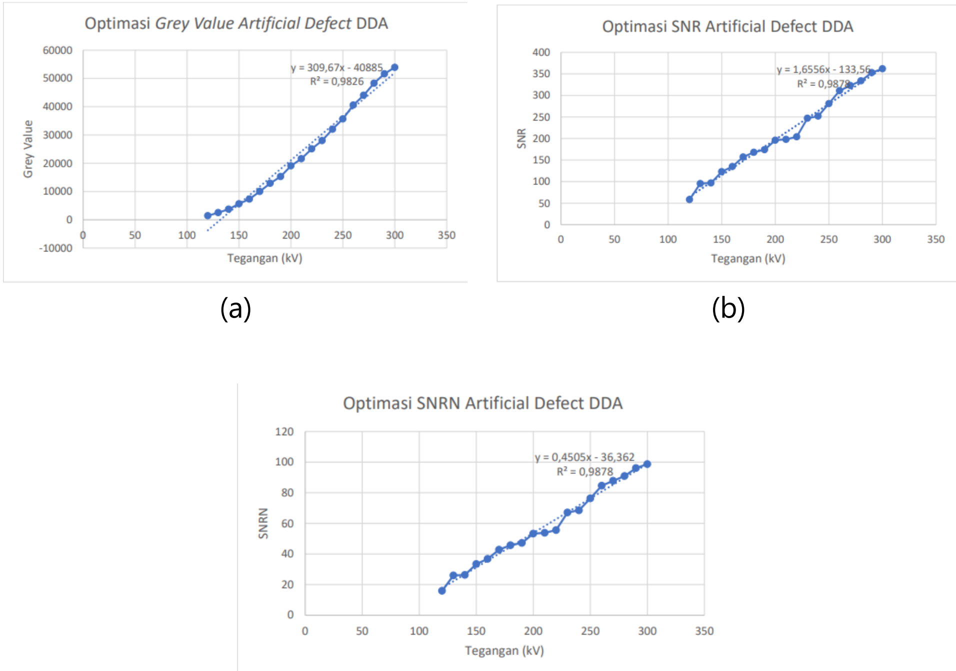


Figure 2. Voltage Optimization for Grey Value, SNR, and SNR_N Using DDA

The image above is a digital radiographic image using DDA with voltage variations of 120kV, 130kV, 140kV, 150kV, 160kV, 170kV, 180kV, 190kV, 200kV, 210kV, 220kV, 230kV, 240kV, 250kV, 260kV, 270kV, 280kV, 290kV, 300kV. It uses a current of 3 mA and 10 frames. Grey Value is the numerical value of the pixels of a digital image used to determine the grayness level of the pixels in the image. The impact of the gray value on the image determines the gray value of each image and produces a linearity graph that shows the relationship between grayness and voltage levels [8]. In particular, the gray value that meets the standard is 50% to 90% of 65,536 or 2^{16} bites [6]. The optimal gray value is at voltages of 240 kV, 250 kV, 260 kV, 270 kV, 280 kV, 290 kV, and 300 kV in Figure 3. The higher the kV, the more energy the X-rays have. This can increase the penetration ability of X-rays so that if the KV is used too high, the image becomes black [9].



(a) (b)

(c)

Figure 3. Voltage (kV) Optimization Graph Against *Grey Value* (a), SNR (b), SNRN (c), On Pipe *Artificial Defect* Using DDA

Figure 3(b) shows the SNR relationship for kV increase. If the kV voltage increases, the SNR value tends to increase. In Figure 3(c), the increase in tube voltage reduces contrast and increases SNRN [10] This is due to its dependence on the kilovolt and milliampere settings for the voltage of the X-ray tube [6].

In Figure 4, the insulated pipe uses DDA. Low kV can be used to see the surface of the insulator. Low kV tends to provide a good image of the insulator material on the pipe. Using 60kV, the resulting image will have enough contrast to distinguish the insulator from the background or other parts of the pipe.

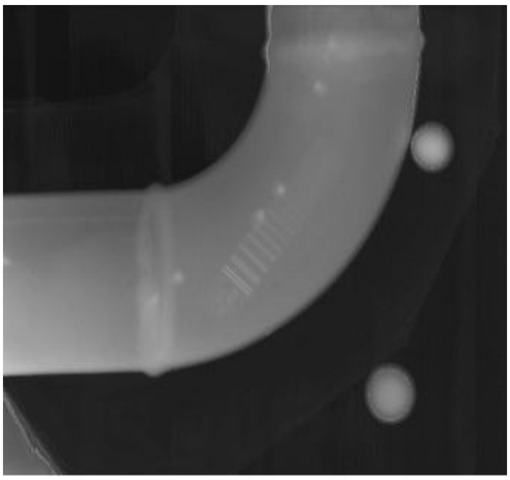


Figure 4. Insulated Pipe Using 60kV to 300kV, 2mA, and 140 frame Digital Detector Arrays

In Figure 5, artificial defect pipes using CR have several voltages, including 240kV, 250kV, 260kV, 270V, 280kV, 290kV, and 300kV. By using different times, can see changes in the image. The image results are slightly different from DDA, where DDA looks clearer and contrasting.

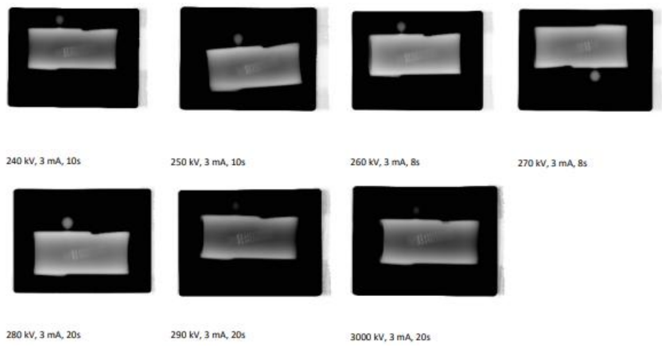


Figure 5. Voltage and Time Variations on Grey Value, SNR, and SNRN of Artificial Defect Pipes Using CR

The results of the grey value artificial defect CR can be seen in Figure 6(a). Exposure time should be increased to increase SNR as compensation [11]. The more Voltage and time increase, the more contrast. In computed radiography, gray values can create visual perception (visibility) as a function of image and noise contrast (SNR or gray values are used instead of optical density and film class systems in radiographic films). Thus, linear initial gray values measure the quantity of radiation penetrating a section of a given area.

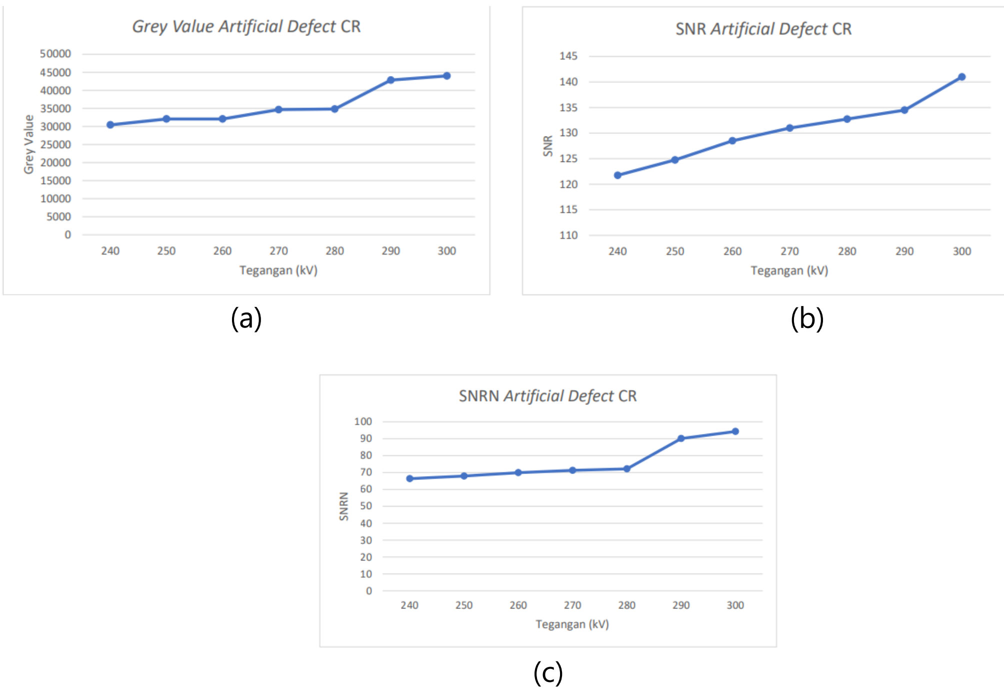


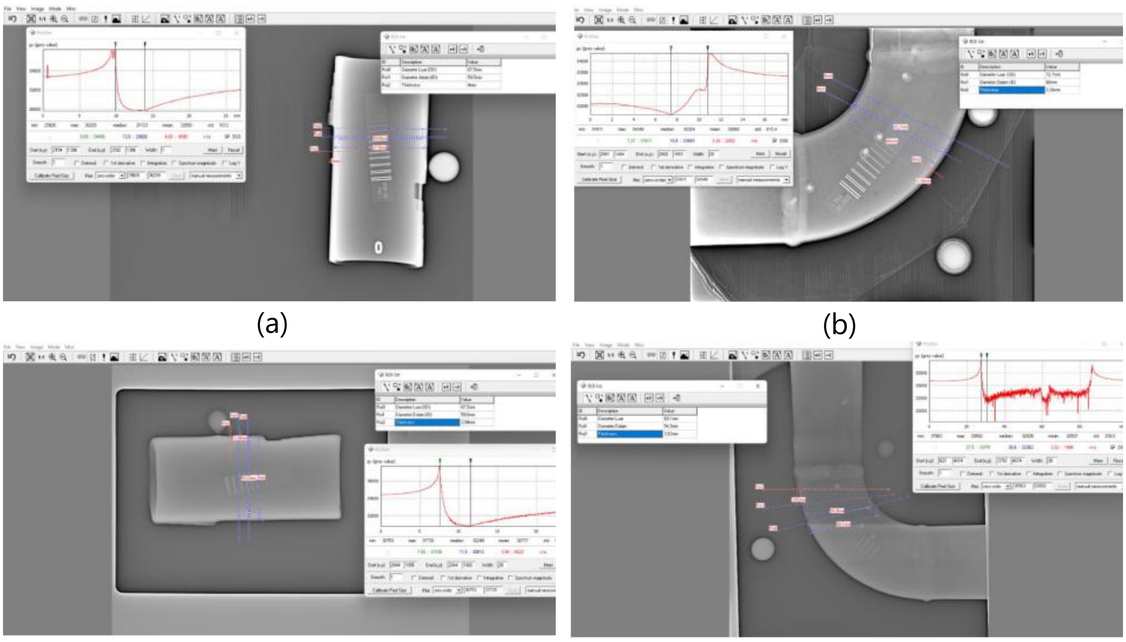
Figure 6. Voltage (kV) Optimization Graph Against *Grey Value* (a), SNR (b), SNRN (c), On Pipe *Artificial Defect* Using CR

In Figure 6(b), the increase in kV affects the increase in SNR. For the same radiation exposure, a non-sharp digital system will achieve a higher measured SNR than a sharp digital system but has a lower performance for fine flaw detection than a sharp system. Figure 6(c) shows that the SNRN at 240 kV and 250 kV is still below 70. For CR, the correlation between SNRN and the average gray value is completely independent of the kilovolt and milliampere settings for X-ray tube voltages above 50 kV up to a few megavolts and gamma-ray sources. This does not apply to DDA [6].

Figure 7. Insulated Pipe Using 180kV, 3mA, and 40 Second Computed Radiography

In Figure 7, to obtain image quality on insulated pipes using computed radiography. Using 180kV, 3mA, and 40 seconds produces 50932 gray values, 209 SNR, and 73 SNRN. The SRB value obtained was 0.25, and the duplex value obtained was D6. There is a bad pixel on the IP, this can happen due to repeated use. Although there are bad pixels, they do not affect the interpretation. It is better to update the IP to minimize the occurrence of repeated shooting [12].

B. Thickness



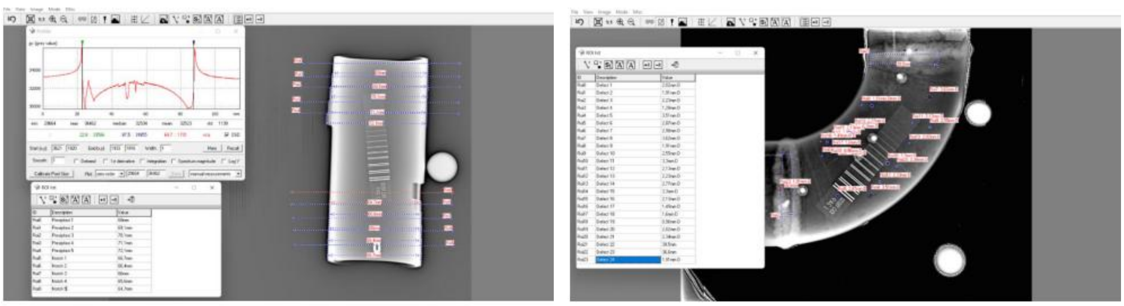
(a) (b) (c) (d)

Figure 8. *Thickness* Pipe *Artificial Defect* using DDA(a), *Thickness* Insulated Pipe using DDA (b), Artificial Defect Pipe Thickness using CR (c), Insulated Pipe Thickness using CR (d)

The results of the ISee software calculation for the thickness of artificial defect pipes using DDA. Figure 8 (a) shows that the outer diameter size is named Roi0, which is 67.5 mm. The inner diameter is named Roi1, with a size of 59.5 mm, and the thickness is named Roi2, with a size of 4 mm. In Figure 8 (b), the insulated pipe is visible in the shape of the pipe and the surface of the insulator, the thickness of the insulated pipe using DDA is 3.38 mm. In the picture, it can be seen that the outer diameter size is named Roi0, which is 72.7 mm. The inner diameter is named Roi1 and is 66 mm in size. The results of the ISee software calculation for the thickness of artificial defect pipes using CR. Figure 8 (c) shows that the outer diameter size is named Roi0, which is 67.5 mm. The inner diameter is named Roi1, with a size of 59.6 mm, and the thickness is named Roi2, with a size of 3.94 mm. In Figure 8 (d), the insulated pipe is visible in the pipe, and the insulator surface is not visible; the thickness of the insulated pipe using CR is 3.02 mm. In the picture, it can be seen that the outer diameter size is named Roi0, which is 60.1 mm. The inner diameter is named Roi1 and is 54.9 mm in size.

Differences in thickness measurements during digital detector array (DDA) and computed radiography (CR) data processing can be caused by several factors. A different detection principle, DDA uses a solid detector such as a semiconductor sensor to detect direct X-rays. The thickness of the material will affect the amount of X-rays absorbed or passed by the object, which is then measured by the detector. CR uses phosphorus to capture X-ray energy, which is then read by the scanner. This process may have different sensitivity to variations in material thickness due to differences in the absorption and dispersion of X-rays by objects. Another factor that can affect the difference in measurement is the maintenance and calibration conditions of the hardware and software. The image quality produced by DDA and CR can also affect the ability to measure thickness accurately. Noise, contrast, and image resolution can affect the clarity and accuracy of measurements. Thus, the difference in thickness measurement in DDA and CR data processing can be caused by several technical and operational factors between the two technologies.

C. Defect Dimensions



(a) (b)

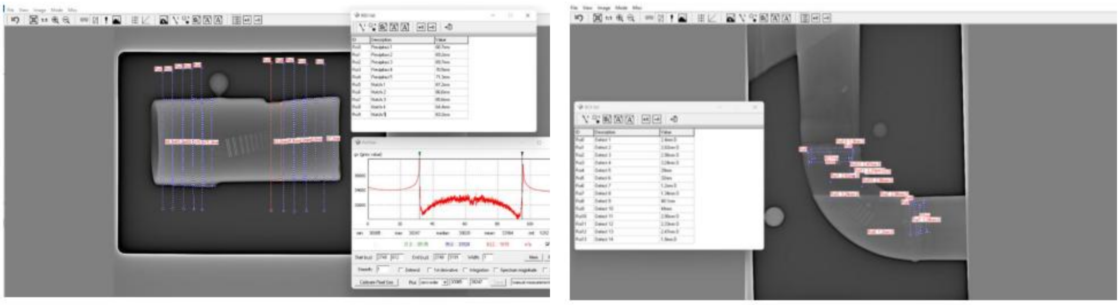
Figure 9. Dimension *Defect* Using *Digital Detector Array* on Pipes *Artificial Defect* (a), and Dimensions *Defect* on Insulated Pipe (b)

In figure 9 (a), the defect dimension in the DDA artificial defect pipe, the result of precipitation 1 is named Roi 0, which is 68 mm; when calculated by reducing the outer diameter, the result of precipitation 1 is 0.5 mm. Notch 1 is named Roi 5, which is 66.7, calculated by the outer diameter minus the Notch value; the result is 0.8 mm. The precipitation and Notch results can be seen in the table.1

Table 1. Defect Dimensions on Artificial Defect Pipes using DDA

No	Presipitasi	*Notch*
1	0.5 mm	0.8 mm
2	1.6 mm	1.1 mm
3	2.6 mm	1.5 mm
4	3.6 mm	1.9 mm
5	4.6 mm	2.8 mm

Figure 9 (b) is the defect dimension found in the insulated pipe using DDA. The total number of defects in the insulated pipe is 24. Among them is an elongated gap (linear indication) in the middle of the welds named Roi 22, with a length of 39.5 mm, and Roi 23, with a length of 36.6 mm. The rounded surface is porous with various sizes, and the black color spreads in any direction throughout the pipe area.



(a) **(b)**

Figure 10. Dimension *Defect* Using *Computed Radiography* on Pipes *Artificial Defect* (a), Dimensions *Defect* on Insulated Pipe (b)

Figure 10 (a) The defect dimension in the DDA artificial defect pipe as a result of precipitation 1 is named Roi 0, which is 68.7 mm, when calculated by reducing the outer diameter, the result of precipitation 1 is 1.2 mm. Notch 1 is named Roi 5, which is 67.2 calculated by the outer diameter minus the Notch value, the result is 0.3 mm. The precipitation and Notch results can be seen in the table.2

Table 2. Defect Dimensions in Artificial Defect Pipes using CR

No	Presipitasi	*Notch*
1	1.2 mm	0.3 mm
2	1.7 mm	0.9 mm
3	2.2 mm	1.9 mm
4	3 mm	3.1 mm
5	3.8 mm	4.3 mm

Figure 10 (b) shows the insulated pipe's defect dimension using CR. The total number of defects in insulated pipes is 14. The resulting image is not so clear, and the duplex parameter as a standard is not so visible because of the bad pixels. The image processing process is carried out using the enhanced details filter. In Figure 10 (b), the defect is not so clearly visible in contrast to Figure 9 (b), which is very clear. Defects are in porosity with a dimension of 3.24 mm, and the smallest is a dimension of 1.2 mm. There is an elongated gap (linear indication) in the middle of the welds named Roi 8 with a length of 40.1 mm and Roi 9 with a length of 44 mm.

D. Element Composition in Pipes

The composition of pipe elements was tested using an X-ray fluorescence test device (EDXRF). The EDXRF spectrometer has a detector capable of measuring a wide range of characteristic energies of radiation coming directly from the sample [13]. The following data on the results of testing the composition of pipe elements can be seen in the table.3

Table 3. Pipe Element Composition Using XRF

No	Jenis Unsur	Persentase Unsur XRF
1	Besi (Fe)	94%
2	Natrium (Na)	2,93%
3	Silikon (Si)	0,601%
4	Mangan (Mn)	0,432%
5	Fosfor (P)	0,336%
6	Aluminium (Al)	0,312%
7	Belerang (S)	0,229%
8	Magnesium (Mg)	0,205%
9	Kobalt (Co)	0,186%
10	Seng (Zn)	0,173%
11	Klorin (Cl)	0,170%
12	Kalsium (Ca)	0,140%
13	Zirkonium (Zr)	0,0803%
14	Kromium (Cr)	0,0541%
15	Nikel (Ni)	0,0371%
6	Tembaga (Cu)	0,0303%
17	Timbal (Pb)	0,0099%
18	Arsen (As)	0,0077%
19	Platina (Pt)	0,0050%
20	Raksa (Hg)	0,0046%
21	Karbon (C)	0,057%

Generally, the carbon content in some types of steel reaches 0.04% to 2.0% depending on the type and classification. By knowing the carbon content, you will see a difference in the value of toughness. Steel with a lower carbon composition will have better toughness than steel with more carbon content [14]. Based on the results of XRF, it is known that insulated pipes have a Fe content of 94% and a C of 0.057%. The results show that insulated pipes are included in the low-carbon steel group. The high Fe content in insulated pipes also contributes to the increased absorption of X-rays. Ferrum is a relatively atomically heavy element, so it has a high absorption of X-rays, when X-rays pass through pipes with a high Fe content, more X-rays will be absorbed by the material, causing a decrease in the intensity of X-rays reaching the imaging plate or detector on the pipe.

CONCLUSION

Based on the test results, it is known that the image quality using DDA with a voltage of 240 kV produces the most optimal contrast resolution, so the image quality produced is better and faster compared to the CR method. The results of the thickness dimension measurement using the DDA method on insulated pipes are 3.38 mm, and on insulated pipes with artificial defects are 4 mm. Compared with the CR method, the values are 3.02 mm and 3.94 mm, respectively. The smaller difference in measurement results in the DDA method shows that this method is more accurate. From the calculation of the ISee software, it is also known that the DDA method can detect a greater number of defects, namely 24, compared to the CR method, which has only 14. The difference in measurement results is due to the difference in the voltage of the X-ray tube, the resolution, and the detector's or IP's sensitivity. The results of the XRF test show that the insulated pipe includes low-carbon steel with a carbon content of 0.057% and 94%

ferrum. This high ferrous content contributes to increased X-ray absorption, greatly affecting the images' quality.

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