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Research

Failure analysis of pulverizer pipe elbow in PLTU boiler

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Abstract

Erosion occurs as a result of a number of different mechanisms, depending on the composition, size, shape of the eroding particles, speed, angle of impact, and surface composition of the eroded components. The pulverizer pipe elbow has become worn out due to the pulverized coal fluid abrasion flowing on the pipe, which the type is AISI Grade 1026. This study was carried out on the causes of this damage case. Damage to the elbow in the boiler needs to be analyzed for the failure of the elbow so that the cause of the damage is known so that it becomes a lesson so that the same damage does not occur again. The research aims to : 1. Find out the cause of damage to the pulverizer elbow on the boiler; 2. Know the right maintenance strategy to increase the reliability of pulverizer pipes in boilers; 3. Simulate erosion due to coal particles in the pulverizer pipe using the Autodesk Simulation Computational Fluid Dynamics software program; 4. Analytical calculations of the erosion rate that occurs at the bend of the pulverizer pipe (elbow) in the boiler. The analysis was done by visual observation, hardness testing, metallographic observation, simulation of ANSYS CFD program, and analytically calculation. The result of ANSYS simulation showed that the main factor causing the leakage was erosion corrosion. At the leaking area, the corrosion concentration was higher than other areas, indicated by the red color in that area. From the calculation results, it was concluded that the largest erosion rate occurs at the angle of 200 with the value is 4.9548 x 10- 11 m3 / s, the more smaller the pulverized coal's angle of impact crashed the pulverizer pipe elbow, the more greater the erosion.

Keywords: AISI grade 1026; ANSYS; elbow; erosion corrosion; pipe pulverizer; wear

1. Introduction

Steam Power Plant is one of the largest electricity suppliers in Indonesia. So it has to operate every day which can result in component failure. Generally, failure is associated with fractures, wear and erosion. For example, the hole in the elbow pipe from the High Pressure Heater (HPH) to the deaerator due to excessive erosion which causes a leak. Steam boilers or steam generators or commonly known in the industrial world, popularly known as boilers, are devices for transferring heat generated from the process of heating water by fuel, using coal, natural gas or electrical energy to become steam or steam such as in PLTU (Febriani and Purwanto, 2021). This steam or steam is usually used for industrial processes, propulsion, heating, power generation and others that flow through hot steam conducting tubes to drive turbines or other systems that can support the production process. Steam boilers (boilers) are very widely used in industries such as oil refineries, natural gas industry, refrigeration and power generation (Jefri, 2012). Larger pressure vessels that can supply energy for commercial and industrial operations are called steam boilers. By using complicated fuel systems, they achieve this by boiling water at subcritical pressures. Because of their high pressure and high steam output capacity, steam boilers in some jurisdictions can only be operated on-site by operators who are fully certified and licensed. A steam boiler can be made in either a firetube or a watertube design.

In a firetube design, a steam boiler is a large pressure vessel in which hot combustion gases pass through one or more boiler tubes connected to the front and back plates of the boiler. The Scottish marine fire tube boiler is the most widely used type of fire tube boiler. They used large pipes for the furnace and many small pipes for the boiler. The combustion process creates hot gases that circulate through the pipes and heat the water in the room. This process creates the high temperatures needed to boil the water and start the steam process.

Indeed, this design is reversed with a watertube boiler. While the combustion gases move to heat the water, the water passes through a smaller diameter boiler tube. In the watertube design, the boiler tubes transport hot water between the upper and lower drums (the steam drum and the mud drum), with the resulting steam collecting in the upper drum. Hot gases move across the tubes and out of the exhaust as heat is produced in the furnace area and transferred to the water via two main zones, the furnace zone and the convection zone.

The pipe component plays an important role in the steam power generation system, namely as a medium for conveying powdered coal which is crushed in the pulverizer mill and then distributed to the combustion chamber (furnace). Therefore, if there is a failure that occurs in the pipe it can cause the process of distributing the coal powder in the system to be ineffective.

In fact, many operating pipe components that distribute coal powder experience leaks due to abrasive coal flowing inside, resulting in considerable losses and accidents. To avoid this, the source of the cause of the damage must be found as early as possible, and it is even said to be too late if one of the components has been found to be defective or damaged and caused failure (W. John BJ. and Cane, 1992).

One example of failure in a power plant is the failure of the elbow pipe. This failure can be in the form of a hole which results in a leak due to the thinning process in the elbow pipe. Due to the high temperatures, high pressures, and abrasive environments in which elbow pipes operate, failure can occur. As a result, a number of failure mechanisms can occur, including overheating, pitting corrosion, creep, erosion, thermal fatigue, corrosion fatigue, and stress corrosion cracking.

Failure analysis is an activity or effort to investigate the causes of failure of a component, all indications are studied and examined to get a decision whether the component is worth repairing or not, cases of damage are very detrimental therefore to avoid similar events it is necessary to study the causes the cause of the damage with especially to avoid excessive cost losses. By knowing the cause of the damage, various preventive measures can be taken. These errors are usually caused by dimensional design errors, material errors, placement errors in certain environmental conditions, stress calculation errors and others.

In connection with the leak/rupture of the pipe bend (elbow) in the boiler at the PLTU, this study was carried out on the causes of this damage case. Damage to the elbow in the boiler needs to be analyzed for the failure of the elbow so that the cause of the damage is known so that it becomes a lesson so that the same damage does not occur again. The research aims to : 1. find out the cause of damage to the pulverizer elbow on the boiler; 2. Know the right maintenance strategy to increase the reliability of pulverizer pipes in boilers; 3. Simulate erosion due to coal particles in the pulverizer pipe using the Autodesk Simulation Computational Fluid Dynamics software program; 4. Analytical calculations of the erosion rate that occurs at the bend of the pulverizer pipe (elbow) in the boiler.

2. Material and Methods

2.1. Material

Materials and equipment used in this test are as follows: 1. Material elbows; 2. Non-Destructive Test (NDT) Equipment (Ultrasonic test equipment and Temperature test equipment); 3. Couplant Gel Type; 4. Digital cameras; 5. Circumstances; 6. Hardness Test Equipment; 7. Optical Microscope; 8. Temperature test equipment; 9. Work safety equipment

In addition, the data used in this analysis include: 1) Operational data of the pulverizer pipe elbow at the PLTU during the performance test. Includes data on the components/sub-system installation for 24 hours. 2) Parameters of the PLTU technical data include: operating pressure, design pressure, temperature, dimensions, and other technical data needed in this study. 3) Manual for the operation and maintenance of PLTU elbow pipes (Manual Design).

2.2. Method

Data was carried out to obtain a picture of the reality that occurred at the research location, in this case the PLTU. This is done through interviews, direct observation and measurement, operational data from the central control room, as well as other supporting data from manual books and other relevant literature. The data required includes: daily capacity, speed, temperature data, material data, design and elbow samples.

In this case, non-destructive testing is carried out. Ultrasonic testing was carried out in the first place. Materials are tested using ultrasonic technology to determine their thickness and any potential flaws or defects. Ultrasonic testing methods use sound waves to measure thickness and find flaws. The terms Sonic Testing (ST), Ultrasonic Testing (UT), Ultrasonic Thickness Measurement (UTM), and Ultrasonic Thickness Testing (UTT) are frequently used interchangeably. It is used on metal the most frequently because of how well it conducts sound waves.

This method, which is one of many Non-Destructive Testing (NDT) testing techniques, is frequently used by inspectors to compile information about the condition of an asset without endangering it. In order to transmit sound waves through the material being tested during an ultrasonic test, an inspector will use a probe or another type of transducer. The sound waves will travel through the material if it is free of flaws, but they will bounce off of flaws if they encounter them, revealing the presence of the flaw. The signal from the sound waves can be used by inspectors to visualize the material in three dimensions and calculate the separations between the various defects found within it.

The second test is temperature testing which goal is to find out whether a product can function under extremely hot or cold conditions. Testing can take place with either cyclic temperature exposure or constant temperature exposure.

Third, the point at which a material, asset, or component fails is examined using a testing method called destructive testing. Inspectors test a material using a variety of destructive test methods that will cause the material to deform or completely disintegrate in order to learn more about how the material responds to stress. Destructive testing techniques can be used to determine a component's physical characteristics, such as toughness, hardness, flexibility, and strength. Destructive physical analysis (DPA) or destructive material testing (DMT) are two terms that are almost always used to refer to destructive testing. Destructive physical analysis is a key testing method that establishes the limits of components in order to require precise operating, maintenance, and replacement recommendations. Failure analysis, process validation, material characterization, and engineering critical assessments are examples of common applications for destructive testing (DT) techniques. NDT techniques like digital radiography are also used in DT applications such as failure analysis and process validation.

In order to find the point at which a material will fail, destructive testing aims to deform or destroy the material. In contrast, non-destructive testing employs inspection techniques that cause no physical harm to a material or asset. In various situations, inspectors employ both DT and NDT. For instance, DT is employed to predict the behavior of a component under various types of stress before it is mass produced or used in its intended application. NDT is used to examine an asset that is already in use in order to find damage early and stop operational failures. This test procedure is used to keep track of assets, inform maintenance plans, and find flaws before they get worse.

Fourth, hardness testing of materials is a crucial because it can be used to predict other mechanical characteristics, such as strength. A material's hardness can also be used to predict how strong it will be under tension. Metal hardness can be measured using a variety of standard hardness test techniques, including Brinell, Rockwell, Vickers, and others. The basic method for conducting a hardness test involves pressing down on an indenter that is naturally harder than the test material for 10 to 15 seconds. The pressure footprint left on the test object's surface is then measured, and the hardness value is calculated by dividing the compressive force by the compressed footprint's area. The fifth is metallographic testing. There are numerous applications for metallographic examinations in conventional testing and damage analysis.

This data will be analyzed, in order: 1) Analyze the causes of wear on the elbow pipe pulverizer; 2) Analyze the erosion corrosion rate of the pulverizer pipe elbow; 3) Simulate corrosion erosion of the fluid in the pulverizer pipe using the ANSYS Simulation Computational Fluid Dynamics software program. The process details can be seen in the following Figure 1.

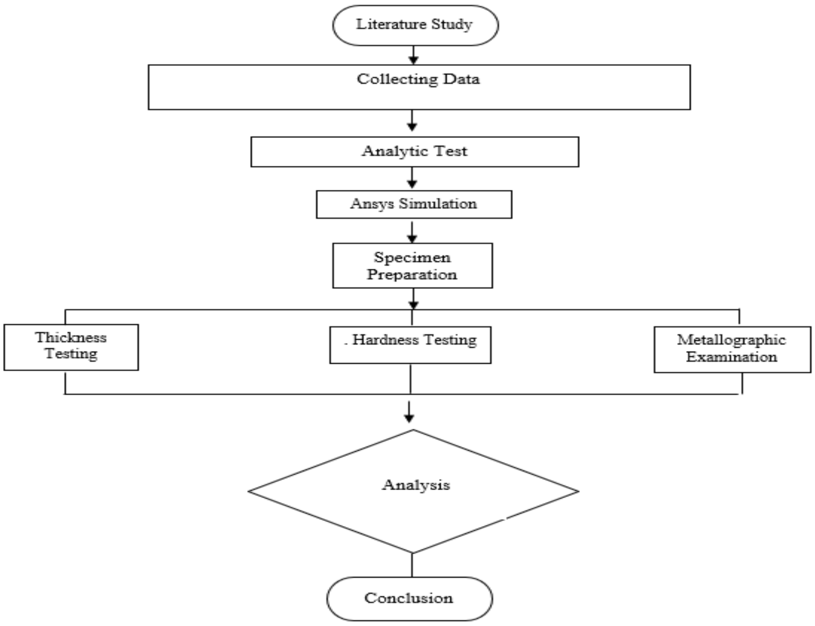


Figure 1. Research Flowchart

3. Results and Discussion

Damage to industrial components and equipment must be immediately and thoroughly handled so that similar damage does not occur in the future. Damage is very detrimental because it can cause the production process to stop, therefore to avoid similar incidents it is necessary to study the causes of the damage. Investigation of the causes of damage will be useful to avoid excessive cost losses. By knowing the cause of the damage, early preventive measures can be taken.

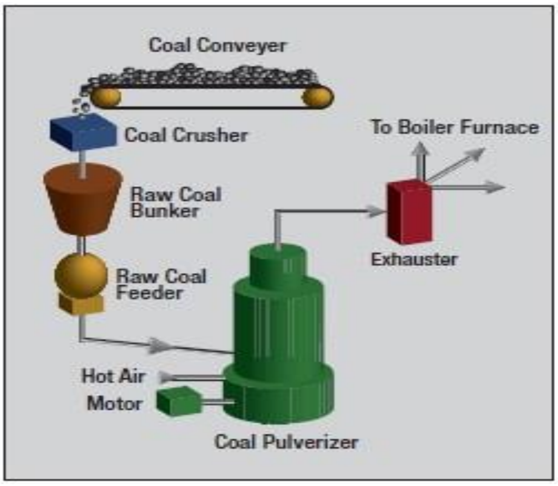


Figure 2. A simple diagram of a coal combustion system

Coal Steam Power Plant (PLTU) is a power plant installation using a turbine engine that is rotated by steam produced by burning coal. The operation of the coal-fired power plant, at first, the coal is fed into the coal tank outside by a conveyor belt, then it is crushed by pulverized coal, and the finely pulverized coal is mixed with hot air by forced draft, high pressure. Cauldron, so that it burns quickly like a flame. The water is then pumped through the tubes in the boiler wall and the water is boiled to steam, which is then pumped into the boiler tubes to separate the steam from the carrier water. The steam is then fed into a superheater, doubling the temperature and pressure of the steam to a temperature of 570 °C and a pressure of about 200 bar, causing the tubes to flash red.To set the turbine to reach the set point, this is done by setting the steam governor valve manually or automatically, the steam output from the turbine has a temperature slightly above the boiling point, so it needs to be channeled into the condenser so that it becomes water ready for re-boiling, while the cooling water from the condenser will be sprayed into the cooling tower causing water smoke in the cooling tower. The slightly cooled water is pumped back to the condenser as cooling water again, the exhaust gas from the boiler is sucked in by a suction fan to pass through the electrostatic precipitator to reduce pollution and the filtered gas is discharged through the chimney (Sutrisna, 2012). The coal that is burned will be refined first in Pulverized fuel coal then channeled into the combustion chamber. More effective combustion is made possible by the process of reducing the coal to a powdery state, which causes the coal to burn like a typical gas. Coal is transported by air or an air/gas mixture, and for combustion, pulverized coal is sent directly into the boiler. Processing coal for this mode of burning requires a number of pieces of equipment. An abstract diagram of this is shown in Figure 2.

The pulverizer is one of the vital components of the coal fuel system which functions to grind, dry and send coal to the combustion chamber (burner). The coal is milled/grinded until it passes through a 70% sieve with a size of 200 mesh. Coal powder (pulverizer coal) that passes will be flowed to the burner. Coal size is maintained at 200 mesh with a temperature of around 650C. This is determined for optimum combustion and preventing self-combustion of coal in the pulverizer. After passing through the mill pulverizer, the coal flows through a pipe to the furnace. The pipe is the medium for the flow of process fluid from one unit to another, in this case the pulverizer pipe transports fine, powdery coal.

Damage can occur on the surface of the pipe in direct contact with various types of organic and inorganic content, contamination, water, moisture and air. This form of shrinkage can be accelerated by factors of temperature, pressure, impact vibration or due to high velocity flow. But in particular the pipe can be damaged because it is caused by the general procedures used to investigate pipe failures are no different from damage to other types of structures. The first step is to find the origin of the fracture, this may be difficult when the pipe fractures are spread along the line for several hundred meters or more, a study of the fracture surface is necessary to find the origin of the fracture (Becker, 2002).

Second, errors in material selection and fabrication are also things that must be avoided so that leaks, cracks and material blockages do not occur. Fabrication errors that usually occur due to poor welding processes, poor heat treatment and the use of tolerances that are permitted outside material standards.

Third, wear which is a condition of maintenance handling in a variety of engineering applications which has economic importance and technical consequences. In economic terms, the cost of abrasion treatment has been estimated to be around 14% of the gross national product of an industrialized country. The effects of abrasion are especially evident in the industrial areas of agriculture, mining, mineral processing, and power generation. Wear is also of great concern in various types of machine components. In fact, wear is a major factor in failure thereby limiting the remaining life of a component. An important example is die and mold wear (Bayer RG, 2002). When a solid surface and solid particles interact mechanically, erosive wear results, which is the progressive loss of the original material from the surface. In many engineering systems, including steam and jet turbines, pipes and valves used to transport powdered materials, and fluidized combustion systems, erosion is a serious issue. (Mishra, et.al, 2006). For the electric power sector, solid particle erosion is a significant issue that results in annual losses in productivity, unplanned outages, and repair expenses of about US$150 million (Stein, et.al, 1999). Recognized as a significant factor in downtime in power plants, coal-fired boilers' erosive, high-temperature wear of heat exchanger tubes and other structural materials can represent 50–75% of the total capture time (Hidalgo, et.al, 2001). Maintenance costs for replacing damaged cylinders in the same plant are also very high, and can be estimated at up to 54% of the total production cost.

Erosion can be caused by a number of different mechanisms, depending on the composition, dimensions, shape, velocity, angle of impact, and surface makeup of the material of the eroded components. The tendency for erosion to occur for ductile materials at about 20° to 30° is not always observed. This depends on factors like particle shape and fragmentation. When spherical, non-fracturing particles strike a ductile material at a 90° angle, the maximum erosion rate may occur. When describing the erosion of a given material over time, the majority of mechanistic models only take into account the steady state. Typically, this pattern consists of an incubation phase during which little to no material is removed, then an increase in rate, followed by a steady state. (Bitter, 1963).

Material erosion has been linked to a number of mechanisms, cutting (Finnie, 1960), elastic fragmentation and elastic-plastic fracture, extrusion, fatigue, delamination, deformation and melting (Hutchings, 1981). An even greater number of analytical models have been proposed, but none have ever been completely satisfactory. To show the general trend of modeling erosion, by looking at the empirical formula for erosion (I.M. Hutchings 1979).

Based on the angle at which the particles impact the material, erosion of ductile materials by solid particles can be divided into two parts: eroding and deforming. An erosion cutting component is created by the particle velocity component that is perpendicular to the surface. In that a piece of material is removed by the impact of sharp-edged particles, erosion by cutting is comparable to chip formation in machining. At small impact angles, this component dominates wear rate (Neilson & Gilchrist, 1968). Increasing temperature has a mixed effect on the erosion rate for ductile materials. A large amount of high temperature erosion testing has been carried out to support the gas turbine and coal gasification industries. this assay has provided a large number of results on the effects of temperature. Corrosion can increase or decrease the apparent erosion rate, depending on the degree of oxide or other corrosion product formation and the resistance of the erosion products compared to normal surface materials (Sundararajan and Roy, 1997). If the corrosion products grow slowly and are more erosion resistant than the underlying metal, it may be effective in protecting the metal from erosion. Similarly, deposition of some process materials on the surface may also protect them.

3.1. Data Specification

The general procedures used to investigate pipe failures are no different from damage to other types of structures (Bayer, 2002; Magnée, 1995). A crucial first step in a successful failure investigation is getting the materials to the investigator in a preserved, undamaged condition. For failures involving tiny parts or brief pipe lengths. This research first step is to find the origin of the fracture, this may be difficult when the pipe fractures are spread along the line for several hundred meters or more, a study of the fracture surface is necessary to find the origin of the fracture (Becker, 2002). In the workings of a Steam Power Plant (PLTU) there are components that support its performance so that it runs according to operational standards. One of them is an elbow pipe which functions to drain steam (steam) from the High Pressure Heater (HPH) to the Deaerator. In this study, the elbow pipe under study experienced a failure in the form of a hole. So that there is a leak when steam flows in it. In order to examine the damage to the elbow on the pulverizer pipe, the test results will be compared with the existing literature. The technical data regarding the elbow on the pulverizer pipe can be seen in Table 1 as follows.

Table 1. Elbow technical data on Pulverizer pipes

Elbow technical Part	Specification
Elbow material	Cast Iron
Initial Elbow Thickness	37,2 mm
Outside Diameter	295 mm
Inside Diameter	257,8 mm
Year Started	2016
Design Temperature	80°C
Class	Alloy_LE_FP
Grades	C-1026 (1.71)

Moreover, Operational data on the PLTU pulverizer pipe can be seen in the following table (Table 2).

Table 2. Operation Data

Operation Period	Design Pressure (mmwg)	Elbow Temperature Design (°C)
1	300	80
2	300	80

3.2. Visual observation

Before moving the specimen, it should be captured on camera or sketched (Visual observation). After the pipe has been taken out of the ditch, pictures should also be taken. In addition to the date and time the photo was taken, it is a good idea to label each image with the test section, failure number, and other information. The results of visual observations on the pulverized pipe that is being installed shows that on the surface of the pipe there has been loss of metal which is indicated by a leak on the surface of the pipe so that a patch is made on the pipe as shown in the Figure 3 below.

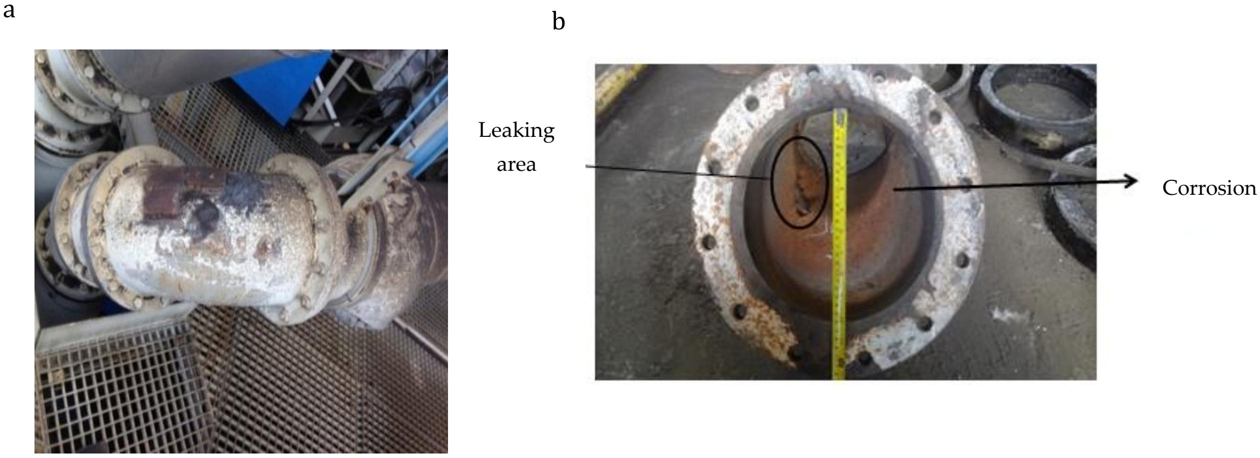


Figure. 3. (a) The condition of the pulverized pipe in operation; (b) Observation of the pulverizer pipe elbow on the inside

From the results of observations focused on pulverized pipes in the field that are no longer used, it shows that in general these pipes have suffered wear damage due to abrasive powdered coal fluid flowing in the pipe due to the abrasive flow of powdered coal fluid flowing in the pipes and based on the chronology of the pulverized pipes, they have undergone pipe replacement (re-piping). and repairs by patching using silicon so that the pipe can still operate.

3.3. Hardness Testing

Due to the fact that it can be used to calculate other mechanical properties, such as strength, hardness is a crucial mechanical property. A material's hardness can also help to avoid a material's tensile strength value. Metal hardness can be measured using a variety of standard hardness test techniques, including Brinell, Rockwell, Vickers, and others. Fundamentally, the hardness test is conducted by pressing down on an indenter that is naturally harder than the test material for 10 to 15 seconds. The pressure footprint left on the test object's surface is then measured, and the hardness value is calculated by dividing the compressive force by the compressed footprint's area.

The hardness test is testing the hardness value of a material, in which this test we can find out the description of the mechanical properties of a material/material. Even though measurements are only made at a point, or a certain area. The hardness value will determine, describe the strength of a material. By carrying out a hardness test of the material, we can determine the hardness, strength and properties of the material; Brittle, Flexibility and for advanced material analysis such as the condition of the "microstructure" of the metal material itself.

The hardness test is carried out on cross sections and longitudinal sections or on the abrasive surfaces of the elbows and the elbow sample material, obtaining data for each part of the figure (Figure 4).

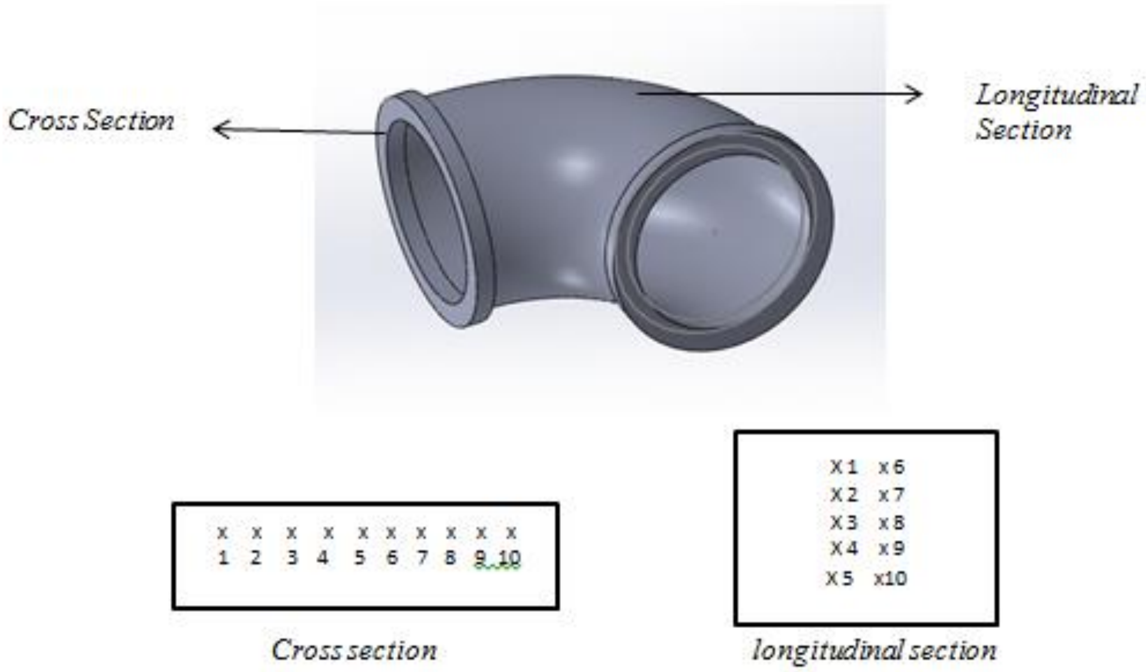


Figure. 4. Hardness testing sketch

Table 3. Hardness test results

Cross-Section Number	Hardness(HVN)	Logitudinal-Section Number	Hardness(HVN)
1	185.8901303	1	208.49245
2	155.0162904	2	196.5204364
3	185.8901303	3	200.2671669
4	181.8782312	4	193.9599369
5	173.9265034	5	195.7837157
6	187.9460424	6	219.834077
7	171.7933908	7	180.8955501
8	156.5807846	8	210.9357001
9	187.9460424	9	170.5920421
10	186.2304325	10	202.1808413

It can be seen from the table above that the hardness value in the sample has a nominal minimum hardness value of 155.01 HV in the cross section and 170.59 HV in the longitudinal section. If the hardness value of the elbow material is harder than the hardness value of the coal particles, then the elbow material will be more resistant to abrasiveness. While the hardness value of coal is 59 HGI, this shows that the elbow surface material is harder than the coal particles flowing in the pulverizer pipe.

3.4. Metallographic Examination

The weld, the entire heat-treated zone, and the parent material on both sides of the weld should all be visible over the full wall thickness when specimens for metallographic examination are taken from HFW and SAW pipe. Microscopically examining at least one specimen under non-sour service and two specimens under sour service from a single pipe in each heat, or after each production pause, whichever occurs more frequently. Examination of the microstructure of the elbow material/material sample was carried out by observing the microstructure before etching and after etching, namely in the Cross section and Longitudinal section of the elbow sample which was damaged (Figure 5).

a b

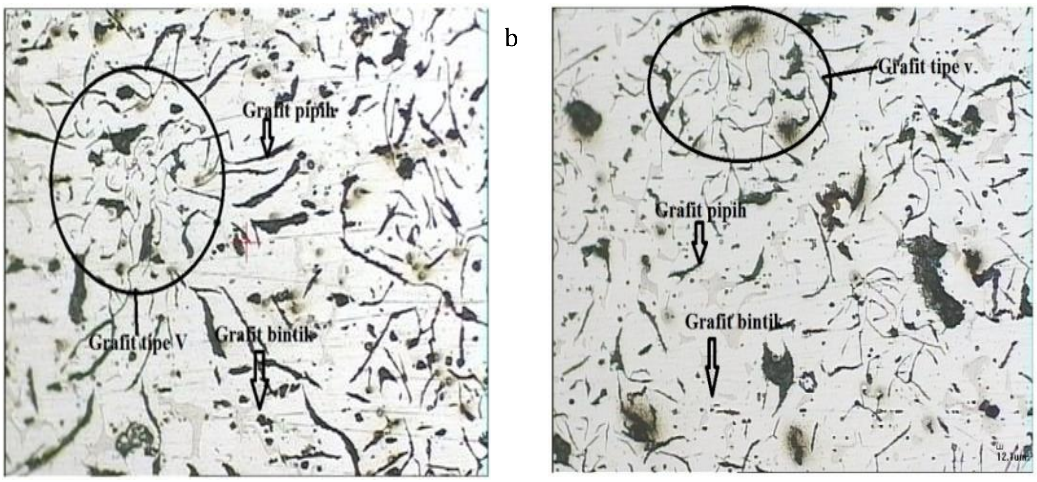
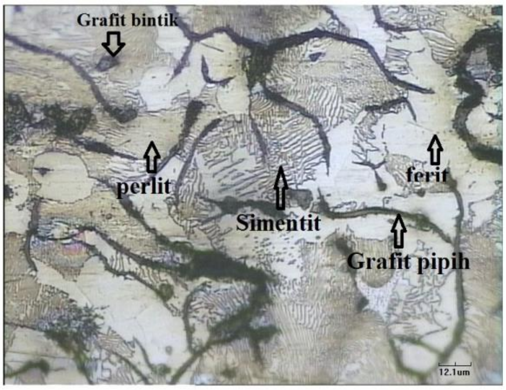


Figure. 5. (a) Cross section before etching 100x magnification; (b) Longitudinal section before etching 100x magnification

The results of microstructural observations on elbow samples in the cross section and longitudinal section before etching showed that the gray cast iron was flake graphite type V (with star-like graphite). From the picture above it can be seen that the condition of the sample is not good, there are lots of nodules and corrosion which indicates that the elbow has many indications of defects caused by abrasives caused by coal particles flowing in the pipe, especially in the longitudinal section there is a lot of corrosion and nodules. so that the microstructural image of the sample is somewhat different from the microstructural image of gray cast iron in general. The microstructure was carried out at three points in each cross section and longitudinal section, from the figure above it shows that from microstructural observations before etching on the elbow samples which were directly affected by the abrasive the results showed that there were many defects in the samples.

The results of observing the microstructure after etching show that the microstructure of the elbow material is ferrite (white), pearlite (black), cementite and graphite. Ferlite has clay properties, pearlite is ductile and has excellent wear resistance, so cast iron is a very suitable material for pipes. Cementite is very hard so that cementite deposition causes wear resistance. Graphite is a soft and brittle crystalline form of carbon. The state of the pieces of this graphite has a great influence on the mechanical properties of the casting, with graphite in the form of flakes causing stress concentrations at the edges (Figure 6).

a



b

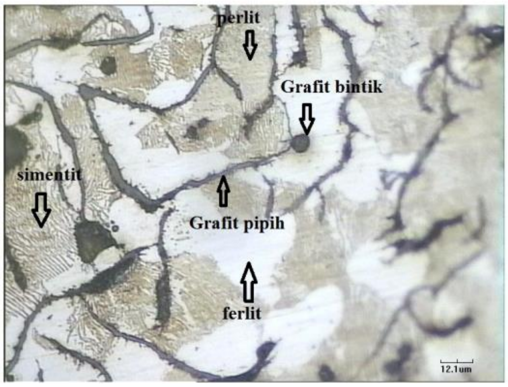


Figure. 6. (a) Cross section after etching magnification 500x; (b) Longitudinal section after etching magnification 500x

3.5. Analysis Using the ANSYS CFD Program

All fluid processes, including fluid-structure multiphysics interactions, can be modeled and simulated using Ansys CFD software. The combustion of gas in automobile engines, the movement of chemical solutions through pores in shale gas formations, the passage of air through the turbine of jet engines, and the transfer of heat between printed circuit board components are all projects that would benefit from the use of this potent CFD software.

The use of ANSYS software aims to determine the factors causing damage to the pulverizer pipe elbow and to find out the affected area caused by coal particles flowing in the pulverizer pipe. The simulation is carried out with a fluid that has two phases, namely in this case the coal particles and air which are blown using a blower, so that the fluid has a different viscosity and density between the coal particles and the air. Fluid simulation computerized data can be seen in table 4 below.

Table 4. Fluid Properties

Characteristics	**Value**
Temperature (°C)	80
Pressure (Pa)	300
Speed (m/s)	1,914
Coal Density (kg/m^3)	121,315
Coal Viscosity (kg/m.s)	59,860
Air Density (kg/m^3)	1,225
Air Viscosity (kg/m.s)	1,7894 x 10^{-5}

This stage is the last stage in the analysis using ANSYS software, the results that will be displayed are images of the object being analyzed. There is a color difference that aims to distinguish the maximum and minimum values from the analysis results. The results of the ANSYS modeling for analyzing damage to the pulverizer pipe elbow can be seen in the following figure.

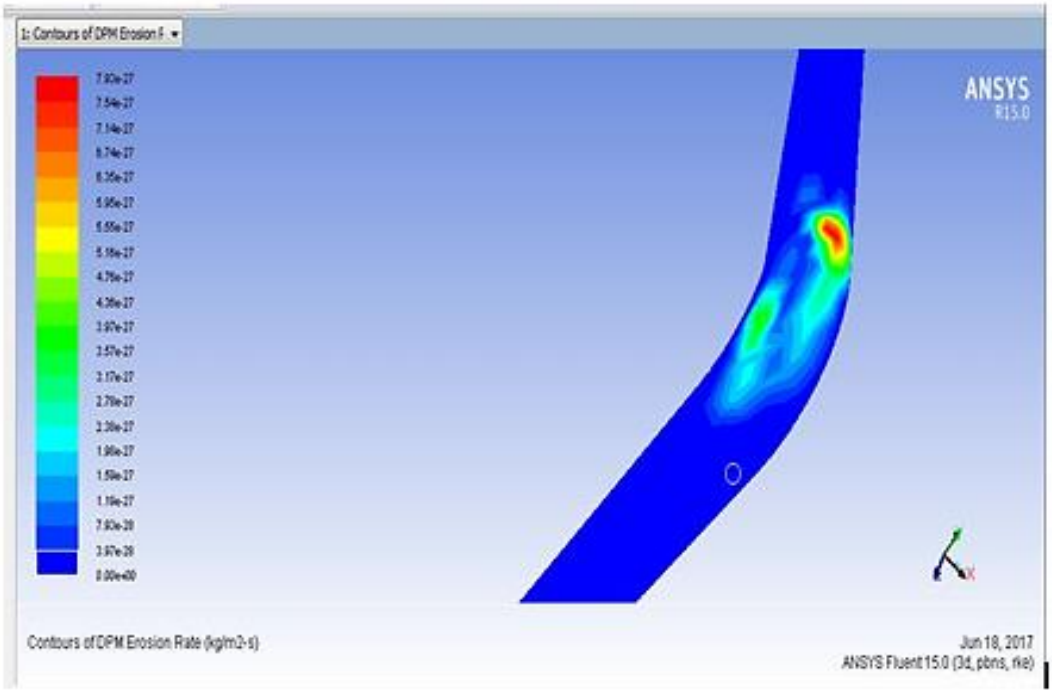


Figure. 7. ANSYS erosion corrosion modeling

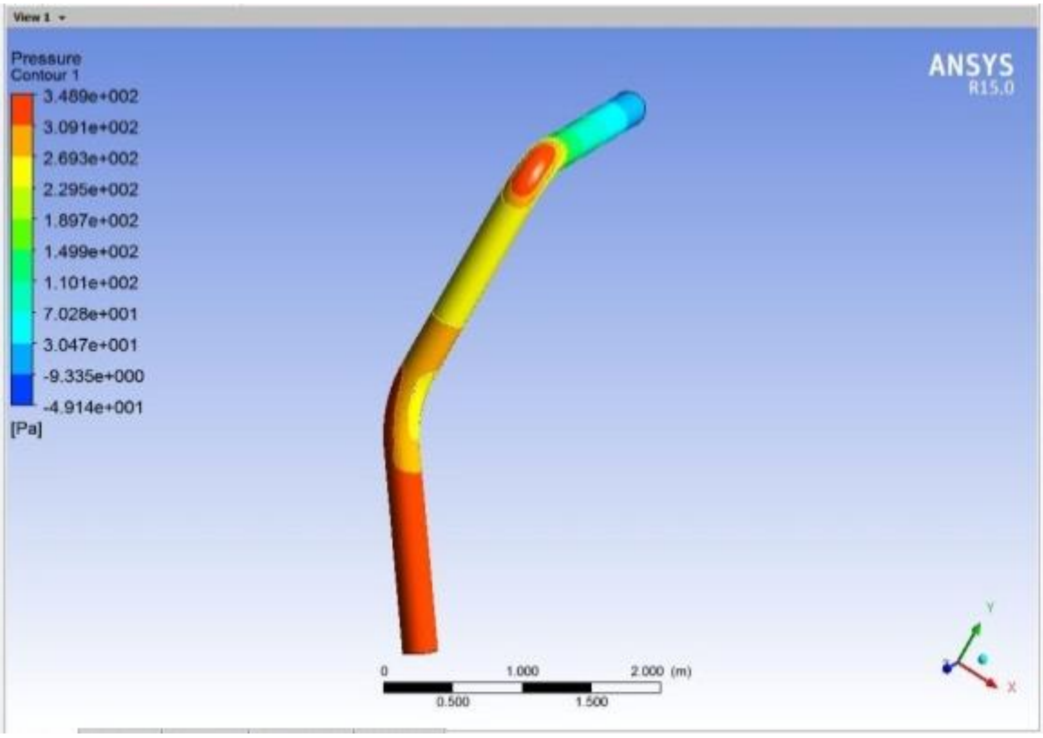


Figure. 8. ANSYS pressure contour modeling results

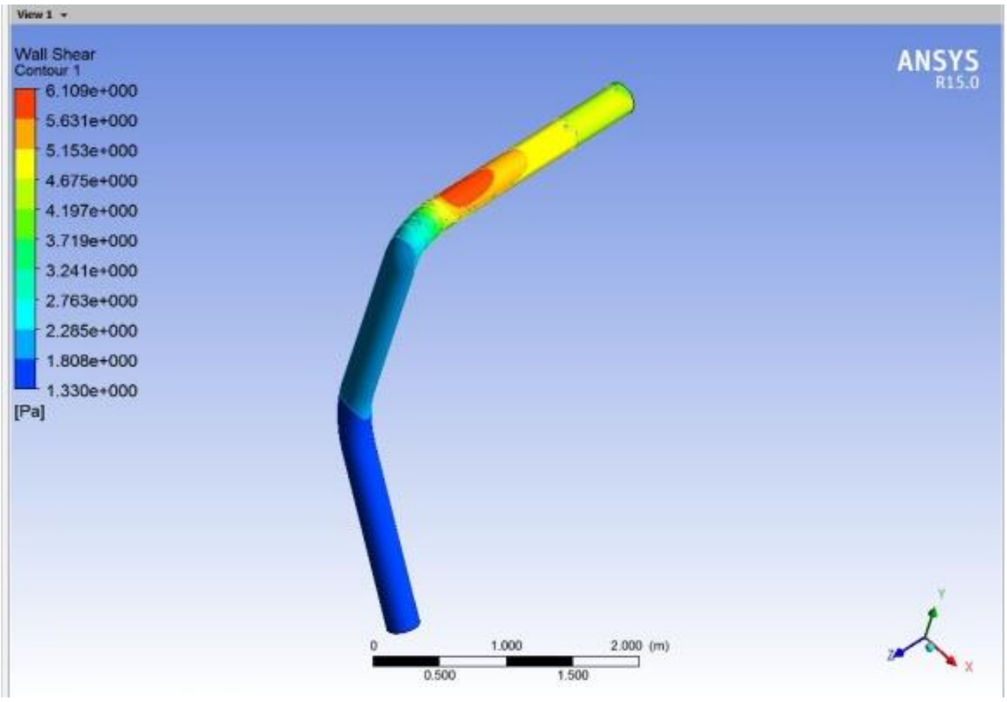


Figure. 9. Results of ANSYS shear stress contour modeling

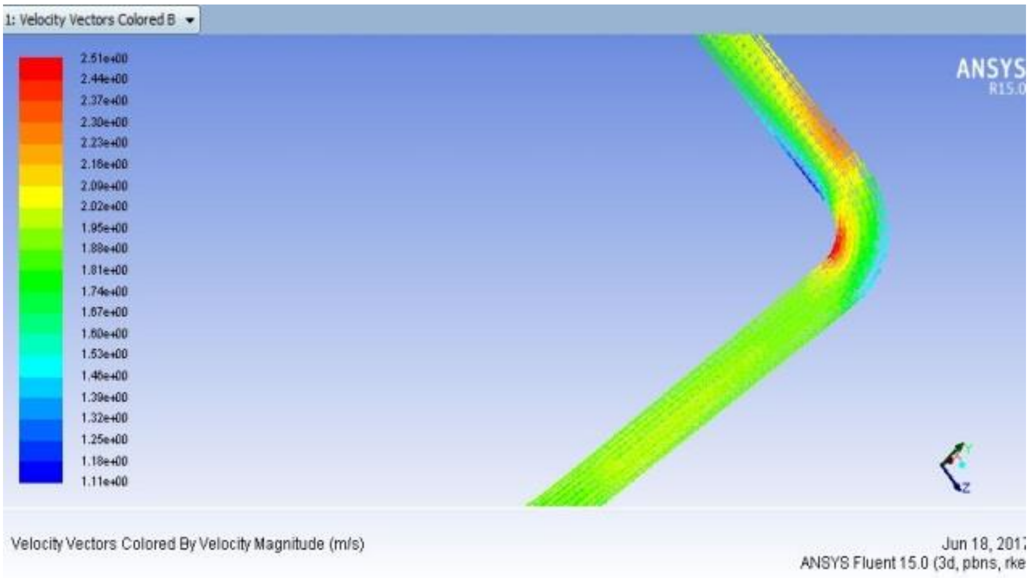


Figure. 10. ANSYS speed vector modeling results

The results of the ANSYS simulation in the figure above show that the main factor causing the leaking of the pulverizer pipe elbow is erosion corrosion as shown in the figure, in the leaking area the concentration of corrosion is higher than in other areas, which is indicated by the presence of a red color in the area. Areas affected by erosion corrosion are marked in light blue, green, yellow and red, the magnitude of the maximum erosion corrosion value that occurs in the pulverizer pipe elbow with an erosion rate of 7,93 x 10^{-27} kg/m^{2}s.

3.6. Erosion Corrosion Rate Analysis on Pulverizer Pipe Elbow

In the literature, there are few studies that adequately examined the application in defining erosion-corrosion due to the complicated nature of the process. In this method, the calculation of the accumulated damage that has occurred in the elbow material is carried out. During its use, of course, the material in the elbow will experience wear caused by coal particles flowing in the pipe. The data can be shown in Table 5 below.

Table 5. Erosion rate at elbow

No	Corner (°)	Erosion Rate (m^2/s)
1	20	4.9548×10^{-11}
2	30	4.7741×10^{-11}
3	45	3.1827×10^{-11}
4	60	4.77300×10^{-11}
5	80	$1,91600 \times 10^{-12}$

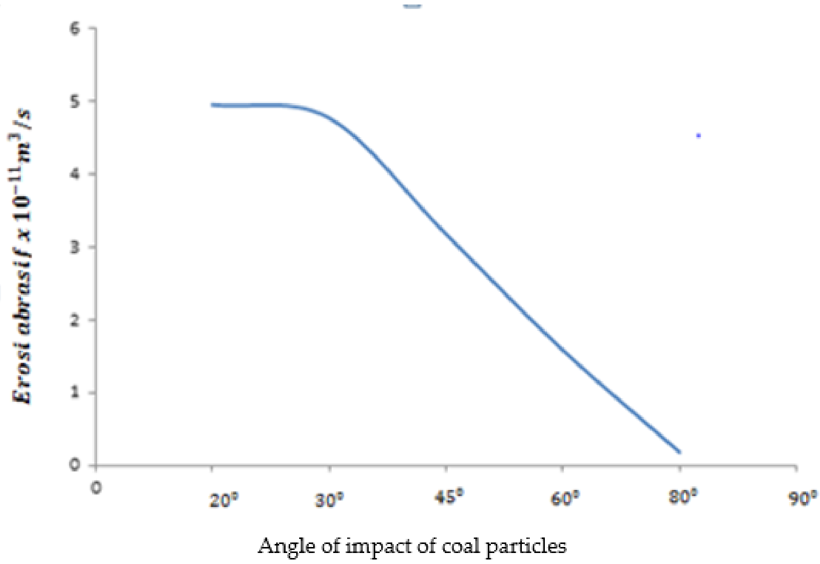


Figure. 10. Graph of erosion rate relationship with impact angle

From the calculation above it can be concluded that the greatest erosion rate occurs at an angle of 20^0 with a value of 4,9548 x 10^{-11} m^3/s, the smaller the angle of impact of coal particles hitting the pulverizer pipe elbow material, the greater the erosion rate that occurs in the pulverizer pipe elbow material. The angle of impact of coal particles on the pulverizer pipe elbow affects the rate of erosion which causes damage to the material.

4. Conclusions

Observations focused on pulverized pipes in the field that are no longer used show that in general these pipes have experienced wear damage due to the abrasive flow of powdered coal fluid flowing in the pipes and based on the chronology of the pulverized pipes, they have undergone pipe replacement (re-piping). and repairs by patching using silicon so that the pipe can still operate. Measurement of elbow thickness using an ultrasonic test and caliper shows that the minimum elbow thickness is 2.70 mm. When compared with the new elbow thickness value of 37 mm. So the thickness is reduced by 34.3 mm. Thus the elbow undergoes a large change in thickness. The hardness value in the sample has a nominal minimum hardness value of 155.01 HV in the cross section and 170.59 HV in the longitudinal section. If the hardness value of the elbow material is harder than the hardness value of the coal particles, then the elbow material will be more resistant to abrasiveness. While the hardness value of coal is 59 HGI, this shows that the elbow surface material is harder than the coal particles flowing in the pipe. After etching the microstructure, it can be seen that the microstructure of the elbow material is ferrite (white), pearlite (black), cementite and graphite. Ferlite has clay properties, pearlite is ductile and has excellent wear resistance, so cast iron is a very suitable material for pipes. Cementite is very hard so that cementite deposition causes wear resistance. Graphite is a soft and brittle crystalline form of carbon. The state of the pieces of this graphite has a great influence on the mechanical properties of the casting, with graphite in the form of flakes causing stress concentrations at the edges. The smaller the angle of impact of coal particles hitting the pulverizer pipe elbow material, the greater the erosion rate that occurs in the pulverizer pipe elbow material. The angle of impact of coal particles on the pulverizer pipe elbow affects the rate of erosion which causes damage to the material. It is recommended that the replacement of pulverizer pipe elbow materials related to wear, pressure and stress is not carried out by looking at the visual conditions only, but other conditions such as data on mechanical properties, metallurgy and thickness are also included in a decision making. To prevent leaks in the pulverizer pipe elbow, you can replace it with a brittle and strong material or coating using a hard and brittle material. The non-isometric flow of coal powder causes the impact angle of the particle impact to the pipe to change, changing the design of the pulverizer pipeline will make the impact angle of the particle impact to the pulverizer pipe elbow to be isometric thus extending the life of the elbow.

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