

Performance Analysis of HP Heater with Comparison of the Number of Plugging Tubes in a 400 MW Coal-Fired Power Plant

¹Akbar Dwitama, ²Widayat, ³M.S.K Tony Suryo Utomo, ⁴Nazaruddin Sinaga

^{1,2,3,4}Master of Energy Department, Diponegoro University, Semarang, Central Java, 50241, Indonesia

¹Suralaya Power Generation Unit (SLA PGU), PT Indonesia Power, Cilegon, Banten, 42439, Indonesia

²Chemical Engineering Department, Diponegoro University, Semarang, Central Java, 50275, Indonesia

^{3,4}Mechanical Engineering Department, Diponegoro University, Semarang, Central Java, 50275, Indonesia

Abstract - Each of Units 1-4 SLA PGU has a capacity of 400 MW and seven feedwater heaters, namely three low-pressure feedwater heaters (LPH 1, 2, and 3), a deaerator, and three high-pressure feedwater heaters (HPH 5, 6, and 7). HPH 5 in Unit 2 has experienced 30% tube plugging, which is equivalent to 480 out of 1579 tubes. Plugging is expected to reduce the performance of HPH. If the plugging exceeds the maximum limit, the HPH needs to be retubed to restore equipment reliability. Furthermore, a comparison of the performance of HPH 5 was calculated with plugging variations of 0%, 22%, and 30% when the unit was at full load. The calculation results of terminal temperature difference (TTD), drain cooler approach (DCA), and log mean temperature difference (LMTD) showed an increase with the increase in plugging in HPH. Meanwhile, the calculation of heat rate and effectiveness showed a decrease caused by the additional plugging in the HPH. The largest heat transfer occurs in the condensing zone of the HPH, where the value is around 80% to 85% of the total heat transfer that occurs. All calculations of the relationship between performance parameters and HPH plugging variations have an R-square value of more than 0.67, indicating a strong relationship.

Keywords: feedwater heater, plugging, performance, heat rate, effectiveness.

I. INTRODUCTION

Electricity is generated by various power plants, including coal-fired power plants, gas-fired power plants, combined-cycle power plants, hydropower plants, diesel power plants, geothermal power plants, solar power plants, nuclear power plants, wave power plants, wind power plants, and biogas power plants. In 2019, Indonesia's total electricity production from both On-Grid and Off-Grid sources reached 295.45 TWh, with coal-based power generation accounting for the largest share at around 59.06% or 174.49 TWh [1].

Fossil fuel-based power plants still play an important role in electricity production through coal-fired power plants. The dominance of coal-fired power plants in electricity production is due to their lower generation costs, which increases the purchasing power of the public and makes industries more competitive [2]. The Ministry of Energy and Mineral Resources (ESDM) has set the benchmark coal price at US\$188.38 per metric ton in February 2022, which has increased by US\$29.88 per metric ton compared to January 2022, which was US\$158.50 per ton [3].

Due to the current high price of coal, conservation measures can be taken by optimizing the equipment in coal-fired power plants to operate reliably and efficiently, thereby saving fuel consumption as much as possible. This is also regulated in government regulations related to energy conservation [4], which are implemented through Energy Management [5], [6].

Wibowo conducted a detailed energy audit at the coal-fired power plant by comparing actual operating parameters with commissioning. One of the audited equipment is the feedwater heater, which showed efficiency losses in the unit due to an increase in the terminal temperature difference parameter [7].

Wang conducted mathematical modeling of a 600 MW coal-fired power plant. Simulation calculations were carried out to utilize drain feedwater heaters as air heaters directed to the air preheater. The simulation results showed an efficiency increase of 41.7%, leading to an increase in power generation capacity up to 627.7 MW [8].

Damayanti conducted a thermal analysis study of high-pressure feedwater heaters in PT. IPMOMI Unit 2, 7 & 8 coal-fired power plants with a total capacity of 2030 MW. The study obtained the effectiveness and pressure drop values with load and plugging variations [9].

SLA PGU units 1-4 are located in the city of Cilegon, Indonesia. SLA PGU is a coal-fired power plant which each unit has a maximum capacity of 400 MW and has five main pieces of equipment, including a Turbine, Condenser, Pump, Boiler, and Generator. To increase the efficiency or performance of the units, additional auxiliary equipment is required. Feedwater heater is one of the equipment in a coal-fired power plant that utilizes the heat of extracted steam from the turbine to increase the feedwater temperature before entering the boiler [10]. Each power plant of SLA PGU has seven feedwater heaters, namely three low-pressure feedwater heaters (LPH 1, 2 & 3), a deaerator, and three high-pressure feedwater heaters (HPH 5, 6 & 7).

In closed system shell and tube feedwater heaters, various types of failures can occur. A study conducted by the Nuclear Plant Reliability Data System (NPRDS) and Equipment Performance and Information Exchange (EPIC) from 1976 to 1996 revealed about 166 incidents related to feedwater heater failures. The most common type of failure, which accounted for 144 incidents or 87% of the 166 incidents, was tube leakage [11].

Tube failures in feedwater heaters can be caused by several factors, including corrosion, erosion, operation and control, and mechanical issues. Corrosion can occur on all types of materials, so the selection of the appropriate material can affect the operational life of the feedwater heater. The materials commonly used for tubes include stainless steel 304, 90/10 CuNi, carbon steel, and chrome moly steels. Areas that have experienced corrosion can easily detach due to the feedwater's high flow rate, forming a characteristic surface known as erosion. The tube inlet is particularly vulnerable to erosion due to the high turbulence in the area, causing impact and peeling of the tube coating. If this continues with varying operation and control frequencies, tube leakage can occur at some point. To maintain the availability of feedwater heater operation, plugging or blocking of tubes that have leaked needs to be done. However, plugging performed on HPH has a maximum limit. If plugging exceeds the maximum limit, HPH will experience a significant decrease in performance so it is required to do retubing [12].

As of March 11, 2022, HPH 5 Unit 2 Suralaya PGU has undergone plugging for 480 tubes or 30% of 1579 tubes. With this condition, it is suspected that there has been a decrease in the performance of HPH.

Next, a comparison of the performance of HPH 5 with variations of plugging at 0%, 22%, and 30% under full load will be calculated. This is done to see how much the variation of plugging affects the performance of HPH.

1.1 The Working Principle of a Coal-Fired Power Plant

On Figure 1, the general principle of how a coal-fired power plant works is shown. The energy conversion process in a coal-fired power plant takes place through three stages:

- a) Chemical energy in the fuel is converted into heat energy that occurs in the boiler equipment in the form of high-pressure and high-temperature steam.
- b) Heat energy (steam) expands in the turbine, producing mechanical energy in the form of turbine rotation.
- c) Mechanical energy in the form of turbine rotation is transmitted to the generator, so that it can be converted into electrical energy and then flowed into the electricity system to be distributed to consumers.

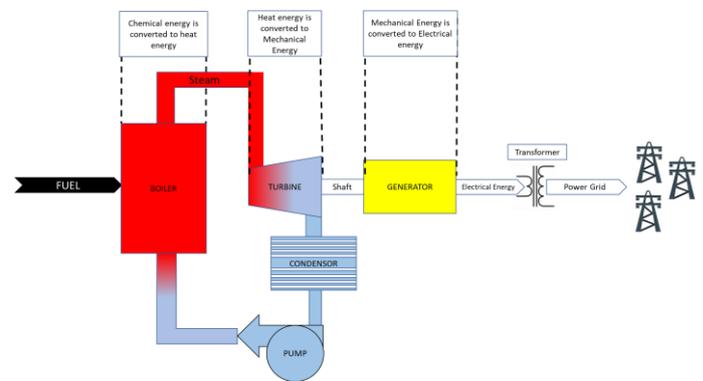


Figure 1: The energy conversion process in coal-fired power plant

1.2 Rankine Cycle of Coal-Fired Power Plant

Rankine cycle is a model of steam engine operation that is commonly used in Coal-Fired Power Plants. The heat source for the Rankine cycle can come from coal, natural gas, oil, nuclear, biomass, and solar thermal energy. The Rankine cycle diagram at Suralaya PGU can be seen in Figure 2 along with its explanation.

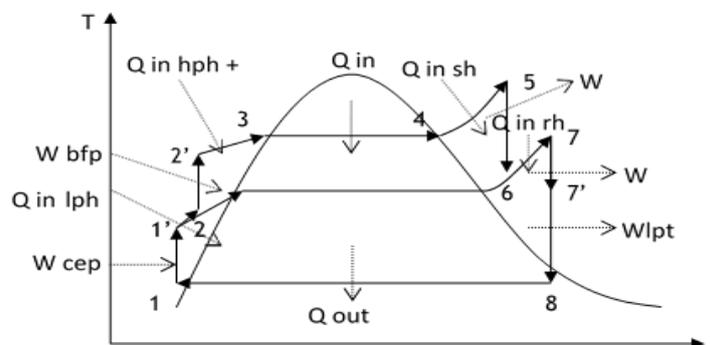


Figure 2: Rankine cycle at Suralaya PGU

- a) Process 1-1': Low-pressure feedwater compression process with a condensate extraction pump from the hotwell condenser to the deaerator tank.

- b) Process 1'-2: Initial feedwater heating process with LPH and deaerator.
- c) Process 2-2': High-pressure feedwater compression process with a boiler feed pump from the deaerator tank to the boiler steam drum.
- d) Process 2'-3: Feedwater heating process with HPH and economizer.
- e) Process 3-4: Process of evaporating saturated water into saturated steam (latent heat) in the downcomer and riser tubes inside the boiler.
- f) Process 4-5: Process of heating saturated steam into superheated steam using a superheater.
- g) Process 5-6: Steam expansion process inside the High-Pressure Turbine.
- h) Process 6-7: Process of reheating steam that comes out from the High-Pressure Turbine, which occurs in the Reheater.
- i) Process 7-7': Steam expansion process inside the Intermediate-Pressure Turbine.
- j) Process 7'-8: Steam expansion process inside the Low-Pressure Turbine.
- k) Process 8-1: Process of steam condensation into water (latent heat) inside the hotwell condenser.

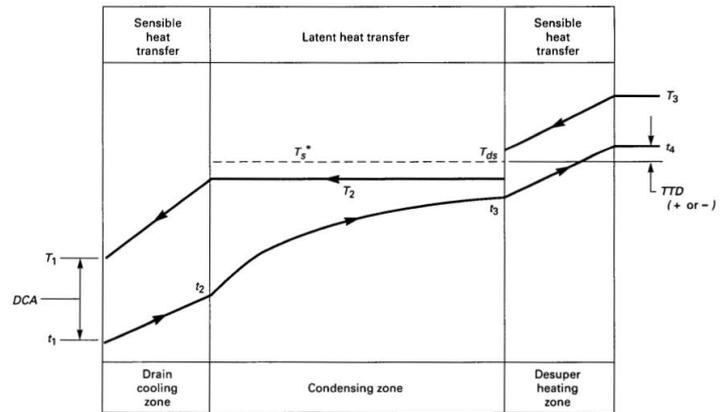


Figure 4: Temperature profile of the 3 zones of feedwater heater [14]

II. RESEARCH METHOD

To facilitate the completion of the research problem on "Performance Analysis of HP Heater with Comparison of the Number of Plugging Tubes in a 400 MW Coal-fired Power Plant", sufficient data is collected when the plugging percentage is 0%, 22%, and 30% in HPH 5.

Operational data sources are obtained from a collection of logging data from March 2021 to March 2022, and then the data is selected at full load of 400 MW. The selected point data for HPH 5 can be seen in Figure 5 while the obtained data is presented in Table 1.

Table 1: Operational data for HPH 5 with plugging combinations of 0%, 22% & 30%

| No | Description | Unit | Tubes Plugging Percentage in HP Heater 5 (%) | | | |
|----|-------------------------------------|--------------------------------------|--|---------|---------|---------|
| | | | 0% | 22% | 30% | |
| 1 | a Feedwater/Condensate water Inlet: | -Temperature (T_{fi}) | (°C) | 145.01 | 144.25 | 144.27 |
| | | -Pressure (P_{fw}) | (Bar) | 192 | 190 | 191 |
| | | -Enthalpy (h_{ci}) | (kJ/kg) | 622.78 | 619.50 | 619.61 |
| | | -Flow (\dot{m}_c) | (kg/s) | 349.82 | 338.68 | 338.68 |
| | b Outlet: | -Temperature (T_{fo}) | (°C) | 175.77 | 173.20 | 169.0 |
| | | -Pressure (P_{fw}) | (Bar) | 192 | 190 | 191 |
| | | -Enthalpy (h_{co}) | (kJ/kg) | 754.42 | 743.23 | 725.23 |
| | | -Flow (\dot{m}_c) | (kg/s) | 355.93 | 338.68 | 338.68 |
| 2 | Bled steam to HPH 5: | -Pressure (P_h) | (Bar) | 8.21 | 8.16 | 8.63 |
| | | -Temperature (T_{hi}) | (°C) | 338.08 | 337.99 | 338.2 |
| | | -Saturated Temperature (T_{sat}) | (°C) | 171.49 | 171.22 | 173.58 |
| | | -Enthalpy inlet (h_{hi}) | (kJ/kg) | 3136.64 | 3136.55 | 3135.97 |
| | | -Enthalpy vapour (h_v) | (kJ/kg) | 2769.36 | 2769.10 | 2771.37 |
| 3 | Drain HPH 6 to HPH 5: | -Temperature | (°C) | 177.1 | 177.1 | 177.1 |

1.3 Feedwater Heater

Feedwater heater is a heat exchanger that functions to provide initial heating to the feedwater by utilizing extraction steam from the turbine. The shell and tube type with U-tubes are chosen because of their ability to handle high pressure and provide a large heat transfer area. Generally, there are three heating zones in the feedwater heater which are divided based on the extraction steam phase, namely the desuperheating zone (dry steam), condensing zone (saturated), and subcooling zone (liquid). The typical division of the feedwater heater zones and their temperature profiles can be seen in Figures 3 and 4.

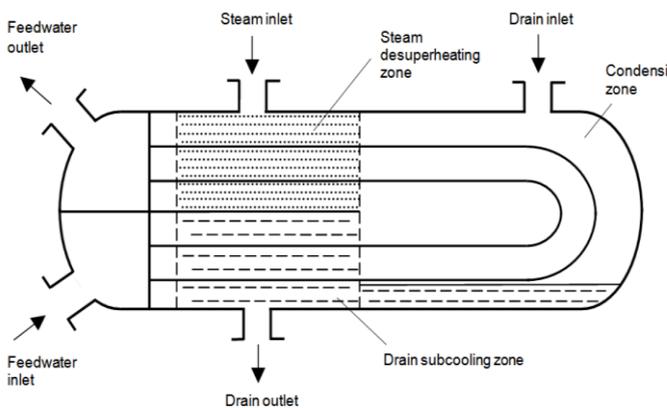


Figure 3: General scheme of the 3 zones division of feedwater heater [13]

| | | | | | |
|---|-------------------------------|---------|--------|--------|--------|
| | -Enthalpy (h_6) | (kJ/kg) | 750.39 | 750.39 | 750.39 |
| | -Flow (\dot{m}_{h6}) | (kg/s) | 47.84 | 47.84 | 47.84 |
| 4 | Drain HPH 5: | | | | |
| | -Pressure (P_h) | (Bar) | 8.21 | 8.16 | 8.63 |
| | -Temperature (T_{drain}) | (°C) | 162.50 | 169.3 | 173.5 |
| | -Enthalpy liquid (h_l) | (kJ/kg) | 725.74 | 724.56 | 734.92 |
| | -Enthalpy outlet (h_{ho}) | (kJ/kg) | 686.54 | 716.15 | 734.76 |

$$T_{cv} = T_{fo} - \frac{\dot{m}_h(h_{hi} - h_v)}{\dot{m}_c C_{pc}} \quad (9)$$

$$T_{cl} = T_{fi} + \frac{(\dot{m}_h + \dot{m}_{h6})C_{ph}(T_{sat} - T_{ho})}{\dot{m}_c C_{pc}} \quad (10)$$

$$\Delta T_{LMTD} = F \left(\frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1 / \Delta T_2)} \right) \quad (11)$$

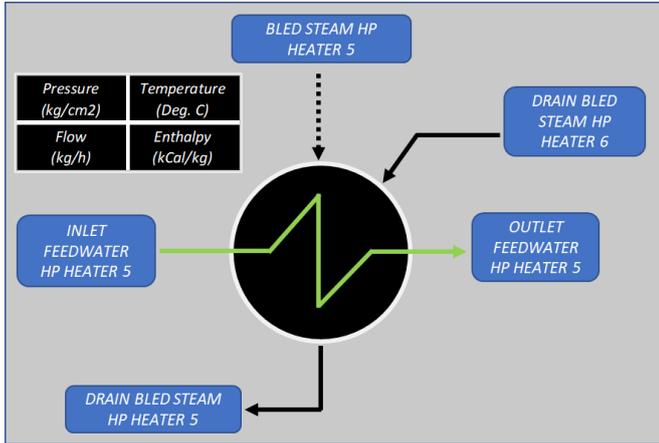


Figure 5: Diagram of selected data point in HPH 5

After collecting the operational data, thermodynamic analysis was conducted to compare the performance of HPH 5 for each variation of tube plugging.

▪ **TTD, DCA & TR [11].**

$$TTD = T_{sat} - T_{fo} \quad (1)$$

$$DCA = T_{ho} - T_{fi} \quad (2)$$

$$TR = T_{fo} - T_{fi} \quad (3)$$

▪ **Heat transfer rate [15]**

$$\dot{m}_h = \frac{\dot{m}_c(h_{co} - h_{ci}) - \dot{m}_{h6}(h_6 - h_{ho})}{h_{hi} - h_{ho}} \quad (4)$$

$$\dot{Q}_{desuperheating} = \dot{m}_h(h_{hi} - h_v) \quad (5)$$

$$\dot{Q}_{condensing} = \dot{m}_h(h_v - h_l) + \dot{m}_{h6}(h_6 - h_l) \quad (6)$$

$$\dot{Q}_{subcooling} = (\dot{m}_h + \dot{m}_{h6})(h_l - h_{ho}) \quad (7)$$

$$\dot{Q}_{Total} = \dot{Q}_{desuperheating} + \dot{Q}_{condensing} + \dot{Q}_{subcooling} \quad (8)$$

▪ **Log Mean Temperature Difference [15]**

To calculate the LMTD in each zone, first the values of C_{pc} and C_{ph} must be determined to find the values of T_{cv} and T_{cl} . C_{pc} is the specific heat value at constant pressure at the average feedwater temperature while C_{ph} is the specific heat value at constant pressure at the average bled steam temperature in the subcooling zone. T_{cv} is the estimated feedwater temperature when entering the desuperheating zone while T_{cl} is the estimated feedwater temperature when entering the condensing zone.

Equation (11) is the formula to find the LMTD value for each zone in the HPH as seen in Figure 6. The correction factor F in the equation can be obtained through the graph in Figure 7.

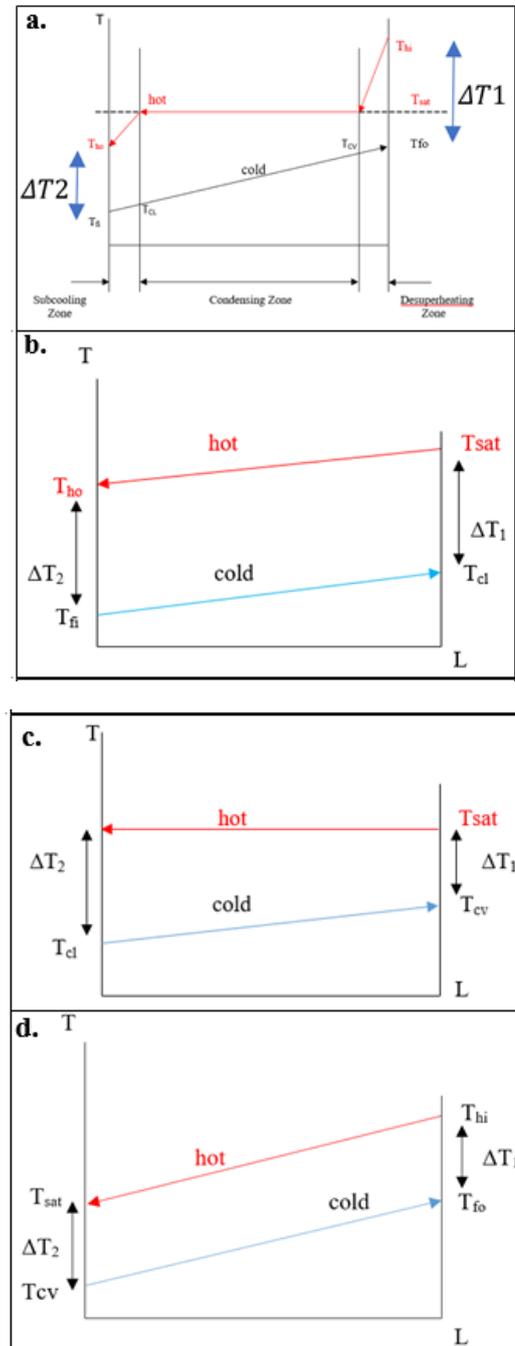


Figure 6: LMTD diagram for total (a), subcooling zone (b), condensing zone (c) & desuperheating zone (d) [14]

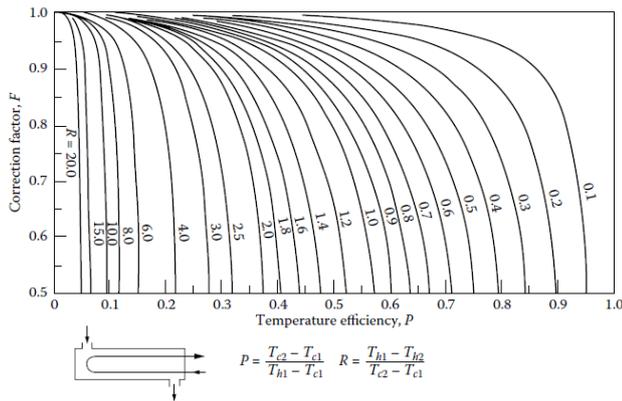


Figure 7: The graph of the LMTD correction factor F for one shell pass and an even number of tube passes [16]

▪ Effectiveness [18]

$$C_c = m_c \cdot C_{pc} \tag{11}$$

$$C_h = m_h \cdot C_{ph} \tag{12}$$

$$Q_{max} = C_{min}(T_{hi} - T_{ci}) \tag{13}$$

$$\varepsilon = \frac{Q}{Q_{max}} \tag{14}$$

The value of C_{min} is the minimum value between heat capacity for the cold fluid (C_c) and hot fluid (C_h). Then, the effectiveness will be calculated for each zone in the HP Heater.

III. RESULTS AND DISCUSSIONS

The thermodynamic calculation results can be seen in the following Table 2.

Table 2: Calculation results of HPH 5 performance with 0%, 22%, and 30% tubes plugging

| No | Description | Unit | Tubes Plugging Percentage in HP Heater 5 (%) | | |
|----|---------------------------------------|--------|--|----------|----------|
| | | | 0% | 22% | 30% |
| 1 | Terminal Temperature Difference (TTD) | (°C) | -4.28 | -1.97 | 4.58 |
| 2 | Drain Cooler Approach (DCA) | (°C) | 17.49 | 25.04 | 29.28 |
| 3 | Temperature Rise (TR) | (°C) | 30.77 | 28.94 | 24.74 |
| | Bled Steam Flow (m_{hi}) | (kg/s) | 17.55 | 16.64 | 14.59 |
| 4 | Total Heat Transfer Rate (Q) | (kJ/s) | 46052.27 | 41905.12 | 35771.16 |
| | -desuperheating zone (Q_{ds}) | (kJ/s) | 6445.62 | 6113.18 | 5317.89 |
| | -condensing zone (Q_{cond}) | (kJ/s) | 37043.62 | 35250.09 | 30443.23 |
| | -subcooling zone (Q_{sc}) | (kJ/s) | 2563.03 | 541.85 | 10.05 |
| 5 | Log mean | (°C) | 65.01 | 74.17 | 79.75 |

| | | | | | |
|--|-------------------------------|----------|----------|----------|----------|
| temperature difference (LMTD) | | | | | |
| C_{pc} | (kJ/kg.°C) | 4.28 | 4.27 | 4.27 | |
| T_{cv} | (°C) | 171.47 | 168.97 | 168.16 | |
| C_{ph} | (kJ/kg.°C) | 4.36 | 4.37 | 4.38 | |
| T_{ci} | (°C) | 146.72 | 144.63 | 144.28 | |
| -LMTD Subcooling Zone Correction Factor (F) | | 1.00 | 1.00 | 1.00 | |
| P Coefficient | | 0.065 | 0.014 | 0.0002 | |
| R Coefficient | | 5.25 | 5.14 | 5.29 | |
| -LMTD Condensing Zone Correction Factor (F) | | 1.00 | 1.00 | 1.00 | |
| P Coefficient | | 1.00 | 0.92 | 0.81 | |
| R Coefficient | | 0.00 | 0.00 | 0.00 | |
| -LMTD Desuperheating Zone Faktor koreksi (F) | | 1.00 | 1.00 | 1.00 | |
| P Coefficient | | 0.026 | 0.02 | 0.00 | |
| R Coefficient | | 38.68 | 39.49 | 194.44 | |
| -Heat capacity desuperheating minimum (C_{ds}) | (kW/°C) | 38.69 | 36.66 | 32.31 | |
| C_c | (kW/°C) | 1496.432 | 1447.52 | 6281.76 | |
| C_h | (kW/°C) | 38.69 | 36.66 | 32.31 | |
| -Heat capacity condensing minimum (C_{cond}) | (kW/°C) | 1496.94 | 1447.94 | 1274.65 | |
| C_c | (kW/°C) | 1496.94 | 1447.94 | 1274.65 | |
| C_h | (kW/°C) | infinite | infinite | infinite | |
| -Heat capacity subcooling minimum (C_{sc}) | (kW/°C) | 285.06 | 281.78 | 273.54 | |
| C_c | (kW/°C) | 1496.48 | 1447.53 | 1445.81 | |
| C_h | (kW/°C) | 285.06 | 281.78 | 273.54 | |
| 6 | Effectiveness Total | % | 90.16% | 80.12% | 70.33% |
| | Q_{max} | (kJ/s) | 51077.31 | 52300.38 | 50864.81 |
| | -Effectiveness desuperheating | % | 99.98% | 98.67% | 96.81% |
| | Q_{max} desuperheating | (kJ/s) | 6446.59 | 6195.61 | 5493.05 |
| | -Effectiveness condensing | % | 99.90% | 91.55% | 81.50% |
| | Q_{max} condensing | (kJ/s) | 37081.25 | 38505.73 | 37353.86 |
| | -Effectiveness subcooling | % | 33.95% | 7.13% | 0.13% |
| | Q_{max} subcooling | (kJ/s) | 7549.47 | 7599.04 | 8017.90 |

Next, the calculation results will be discussed for the relationship between HPH 5 performance and tubes plugging variations of 0%, 22%, and 30%.

3.1 TTD, DCA & TR vs Plugging

Increased plugging in the HPH tubes will reduce the heat transfer surface area for each HPH zone, thus affecting the values of the TTD, DCA, and TR parameters as follows:

- The outlet temperature of the feedwater tends to decrease, causing the TTD value to increase and the TR value to decrease.
- The drain temperature or outlet temperature of the shell side tends to increase, causing the DCA value to increase.

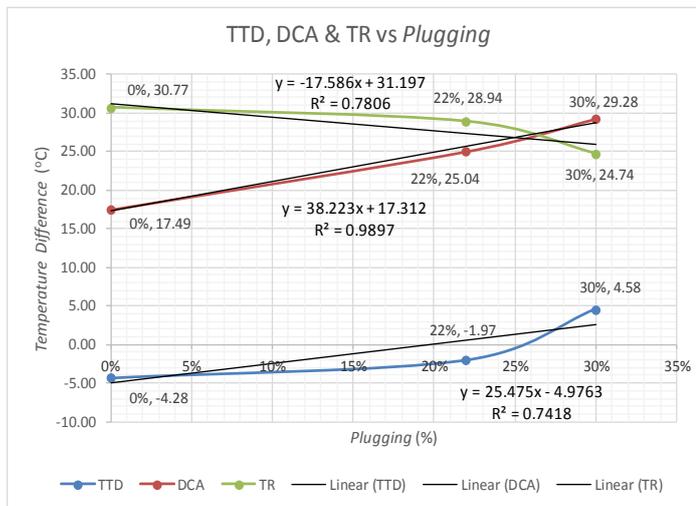


Figure 8: Relationship between TTD, DCA, and TR parameters with tubes plugging variations in HPH 5 Suralaya PGU

It can be seen in Figure 8 that in the TTD and DCA parameters, there is a tendency for values to increase as the percentage of plugging increases, while in the TR parameter, there is a tendency for values to decrease. When the plugging exceeds 22%, the exponential increase in TTD and decrease in TR values becomes more apparent. Meanwhile, the DCA value remains following its trendline when the plugging exceeds 22%.

Linear regression was applied to each curve to obtain the equation of the line and the least square/R-square value. The R-Square value is categorized as strong if it is greater than 0.67, moderate if it is greater than 0.33 but lower than 0.67, and weak if it is greater than 0.19 but lower than 0.33 [17].

For the TTD, DCA, and TR curves, their respective least square values are 0.7418, 0.9897, and 0.7806. All values are above 0.67, indicating a strong relationship between the TTD, DCA, and TR values and the amount of plugging in HPH 5 Suralaya PGU.

3.2 Heat Rate vs Plugging

The relationship between the heat transfer rate and the heat transfer surface area is directly proportional. The more plugging that occurs in the HPH tubes, the more the heat transfer surface area is reduced, resulting in a decrease in the heat transfer rate in each HPH zone.

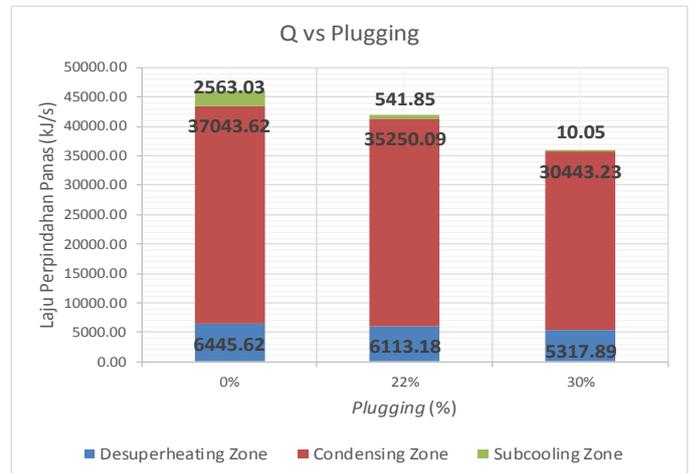


Figure 9: Heat transfer rate values in each zone of HPH 5 Suralaya PGU with tube plugging variations

Figure 9 shows the decrease in the heat transfer rate for each zone as the percentage of HPH tube plugging increases. The following are some details that can be taken from the histogram:

- When the plugging percentage is 20%, the heat transfer rate value in the desuperheating zone decreases by about 5% compared to 0% plugging. And when the HPH plugging is at 30%, the heat rate value in the desuperheating zone decreases by up to 17.50%.
- When the plugging percentage in the HPH is 20%, the heat rate value in the condensing zone decreases by around 5% compared to a plugging percentage of 0%. And when the HPH plugging is at 30%, the heat rate value in the condensing zone decreases by up to 17.82%.
- The reduction in heat rate value in the subcooling zone is the most significant compared to other zones. When the plugging percentage in the HPH is 20%, the heat rate value in the subcooling zone decreases by around 79% compared to a plugging percentage of 0%.
- The highest heat transfer rate occurs in the condensing zone, which is around 80% to 85% of the total heat transfer rate.

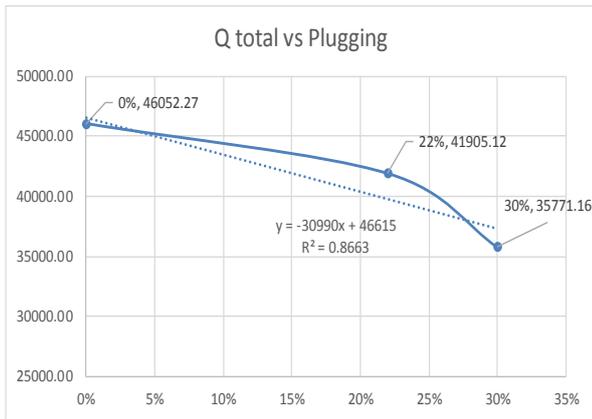


Figure 10: Relationship between total heat transfer rate and tube plugging variations in HPH 5 Suralaya PGU

Figure 10 shows the relationship curve between the total heat transfer rate and tubes plugging variations of 0%, 22%, and 30% in HPH 5 Suralaya PGU. Overall, the value of the heat transfer rate in HPH 5 Suralaya power plant tends to decrease as the percentage of plugging increases.

In the curve, the least square value is 0.8663. This value is above 0.67, indicating that the relationship between the total heat transfer rate and the number of plugging tubes in HPH is categorized as strong.

3.3 LMTD vs Plugging

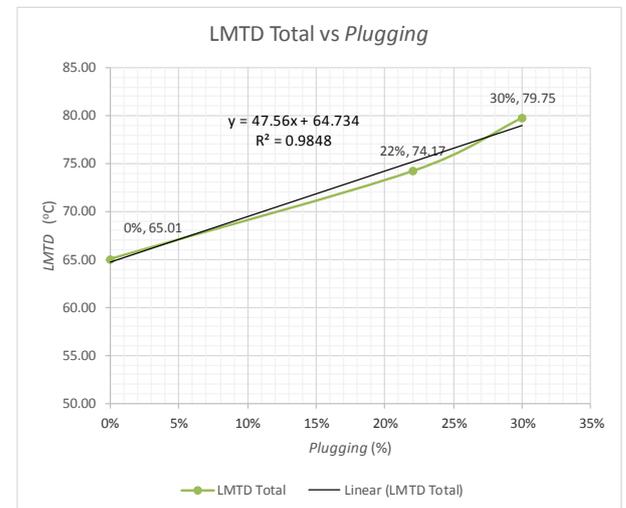
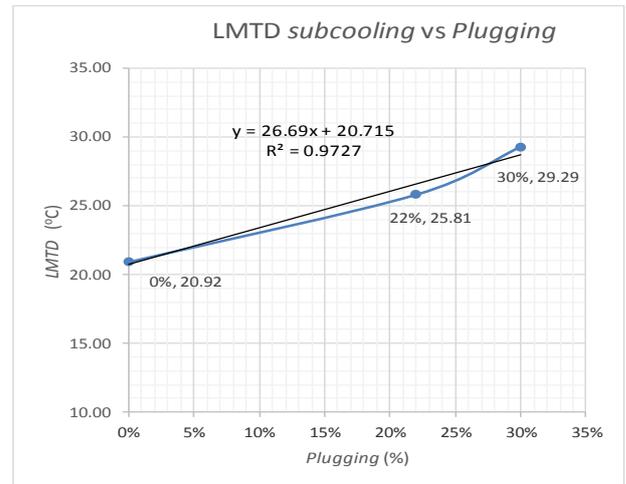
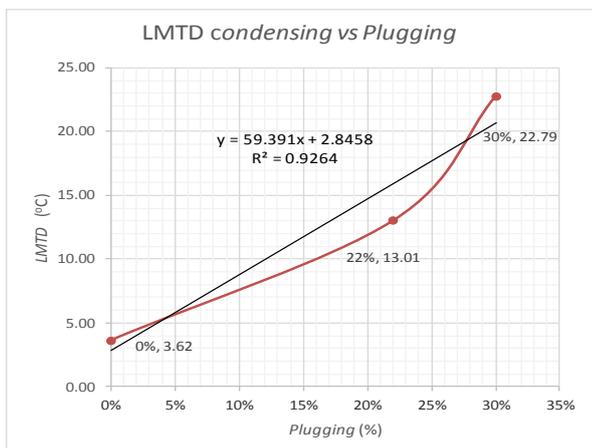
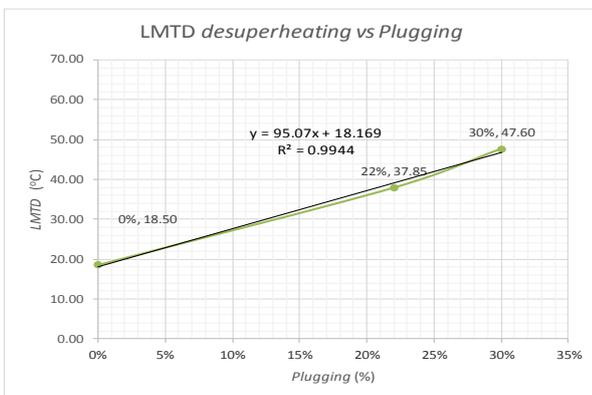


Figure 11: Relationship between LMTD desuperheating, condensing, subcooling & total with tube plugging variations in HPH 5 Suralaya PGU

Figure 11 shows the relationship curves between the total LMTD and each zone with tube plugging variations of 0%, 22%, and 30% are shown. The values of the total LMTD and each zone in HPH 5 Suralaya power plant tend to increase as the percentage of plugging tubes increases. Linear regression is applied to each of the curves to obtain the equation of the line along with the least square/R-square values. For the LMTD curves of the desuperheating, condensing, subcooling, and overall zones, the least square values are 0.9944, 0.9264, 0.9727, and 0.9848, respectively. All of these values are above 0.67, indicating that the relationship between the LMTD values and the number of plugging tubes in HPH is categorized as strong.

When the percentage of tube plugging in a feedwater heater increases to 30%, it can significantly impact the heat transfer performance of the heat exchanger. As the plugging of the tubes increases, the available surface area for heat transfer decreases, which can reduce the overall heat transfer coefficient and efficiency. Tubes plugging can create

turbulence that might enhance the evenness of temperature distribution across the heat exchanger. This lead improvement in the value of LMTD and boost the heat transfer rate. Nonetheless, the impact on the overall heat transfer performance is usually insignificant compared to the decline in heat transfer efficiency caused by tubes plugging. It is important to note that continued fouling or plugging can eventually lead to a complete blockage of the tubes, which can result in a significant decrease in heat transfer performance and potentially cause damage to the heat exchanger. Therefore, it is important to monitor the performance of the heat exchanger and to clean or replace tubes as necessary to maintain optimal heat transfer efficiency [18].

3.4 Effectiveness vs Plugging

The effectiveness of HPH is the ratio of the actual heat transfer rate to the maximum achievable heat transfer rate [19]. As the percentage of plugging in HPH increases, the heat transfer rate also decreases, as seen in Figure 10. This results in a decrease in effectiveness for each zone of HPH as well as for the overall HPH.

The relationship between the heat transfer rate and the surface area of heat transfer is directly proportional. The increase in plugging in HPH reduces the surface area of heat transfer, causing a decrease in the heat transfer rate in each zone of HPH.

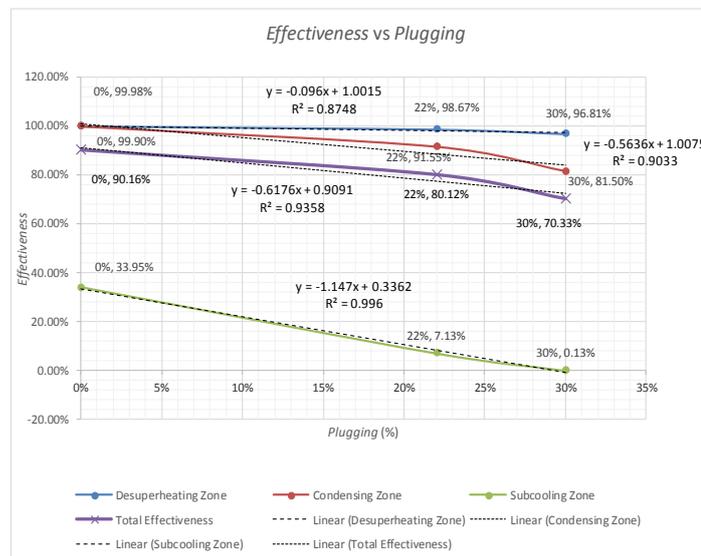


Figure 12: Relationship between total effectiveness and each zone in HPH 5 Suralaya PGU with tube plugging variations

The following are some details that can be taken from Figure 12:

- The effectiveness value in the desuperheating zone with plugging percentages of 0%, 22%, and 30% respectively is around 99.98%, 98.67%, and 96.81%. The

effectiveness value in this zone is the highest compared to other zones. The decrease in desuperheating effectiveness value that occurs is not too significant. This indicates that even though the plugging percentage increases, the heat transfer rate still occurs optimally in the desuperheating zone, where the sensible heat absorption of bled steam by the feedwater occurs almost maximally until the bled steam becomes saturated steam.

- The effectiveness value in the condensing zone with plugging percentages of 0%, 22%, and 30% respectively is around 99.00%, 91.55%, and 81.50%. The decrease in condensing zone effectiveness value from 0% to 22% plugging is relatively gradual, but the decrease becomes significant after the plugging percentage exceeds 22%. The latent heat absorption at 30% plugging percentage does not occur optimally, indicating that there is a certain amount of bled steam mass that does not completely change phase into saturated liquid.
- The effectiveness values in the subcooling zone with plugging percentages of 0%, 22%, and 30% are approximately 33.95%, 7.13%, and 0.13%, respectively. The effectiveness value in this zone is the lowest compared to the other zones. The decrease in effectiveness value in the subcooling zone is significant with an increase in plugging percentage. The sensible heat absorption of bled steam in the liquid phase is not optimal at 22% plugging percentage, and it is worst at 30% plugging percentage. The outlet temperature of bled steam is very close to its saturation temperature, indicating a minimal decrease in sensible temperature and possible cavitation.
- The overall effectiveness value of the HPH with plugging percentages of 0%, 22%, and 30% respectively is around 90.16%, 80.12%, and 70.33%. The significant decrease in overall effectiveness value at 22% and 30% plugging percentages is due to the very low effectiveness value in the subcooling zone.
- On the effectiveness curve of the desuperheating, condensing, subcooling, and overall zones, the least square values are 0.8748, 0.9033, 0.996, and 0.9358 respectively. All of these values are above 0.67, indicating that the relationship between effectiveness value and the number of plugging tubes in the HPH is categorized as strong.

Upon conducting a comparative analysis of the HP Heater's performance while varying the number of tubes plugging, it was noted that the act of plugging said tubes may lead to a decline in the heater's effectiveness. This, in turn, can result in heightened fuel consumption or diminished plant efficiency, as the feedwater temperature may not attain its utmost potential after passing through the HP Heater.

Therefore, regular maintenance and cleaning of the HP Heater tubes are necessary to prevent plugging and fouling. One strategy is to use chemical cleaning agents, such as citric acid or hydrochloric acid, to dissolve and remove deposits from the tubes [20]. Mechanical cleaning, such as using brushes or high-pressure water jets, can also be effective in removing fouling [21]. Furthermore, proper water treatment can help prevent the accumulation of deposits in the tubes [22].

IV. CONCLUSION

The findings of the study reveal that an escalation in plugging within the HPH system leads to a corresponding increase in values for terminal temperature difference (TTD), drain cooler approach (DCA), and log mean temperature difference (LMTD). Conversely, heat rate and effectiveness values experience a decrease in response to an increase of plugging in the HPH system. The condensing zone within the HPH system is responsible for the highest heat transfer, representing approximately 80-85% of total heat transfer. The R-square value for all calculations concerning performance parameters and variations in HPH plugging is greater than 0.67, signifying a robust correlation.

Further research could utilize heat transfer simulation applications to obtain more accurate calculations. Additionally, the research could investigate the impact of increased HPH plugging percentages on boiler and power plant efficiency. Furthermore, a cost-benefit analysis could be conducted to evaluate the feasibility of retubing the HPH.

ACKNOWLEDGEMENT

The authors would like to express their sincere gratitude to Instrument & Control Maintenance division unit 1-4 Suralaya PGU who generously provided access to the data logging system used in this research. Without their kind assistance, this study would not have been possible. We would also like to thank Turbine Maintenance division for providing invaluable references on the data, both from the manual books and from the field.

Furthermore, we would like to express our sincere gratitude to all those who have provided us with constant support and guidance throughout this research project. We deeply appreciate the time and expertise they have dedicated in giving us valuable feedback and constructive criticism, which has significantly contributed to shaping the final outcome of this paper. Their contributions have played an indispensable role in the success of this research.

REFERENCES

- [1] DEN, "Laporan Kinerja Sekretariat Jenderal Dewan Energi Nasional 2020," Jakarta, Jan. 2021.
- [2] R. Indrawan, "Hingga Juni 2021 Kapasitas Pembangkit Listrik Indonesia Mencapai 73.341 MW, Komposisi PLTU Mencapai 47%," Sep. 24, 2021. Accessed: May 18, 2022. [Online]. Available: <https://www.dunia-energi.com/hingga-juni-2021-kapasitas-pembangkit-listrik-indonesia-mencapai-73-341-mw-komposisi-pltu-mencapai-47/#:~:text=Hingga%20Juni%202021%20Kapasitas%20Pembangkit,PLTU%20Mencapai%2047%25%20%2D%20Dunia%20Energi>
- [3] R. Mudassir, "Permintaan Meroket, Harga Batu Bara Acuan Februari 2022 Ditetapkan jadi US\$188,38," Feb. 08, 2022. Accessed: May 19, 2022. [Online]. Available: <https://ekonomi.bisnis.com/read/20220208/44/1497913/permintaan-meroket-harga-batu-bara-acuan-februari-2022-ditetapkan-jadi-us18838>
- [4] Peraturan Pemerintah Republik Indonesia Nomor 70 Tahun 2009 Tentang Konservasi Energi.
- [5] B. L. Capehart, W. C. Turner, and W. J. Kennedy, Guide to Energy Management Fifth Edition, 5th ed. London: The Fairmont Press, Inc., 2006.
- [6] The British Standards Institution, Energy management systems: requirements with guidance for use., 2012th ed. 2012.
- [7] S. A. Wibowo, "Audit Energi Detail Pada PLTU Batubara Dengan Membandingkan Parameter Operasi Aktual Dengan Komisioning," 2021.
- [8] D. Wang, H. Li, C. Wang, Y. Zhou, X. Li, and M. Yang, "Thermodynamic analysis of coal-fired power plant based on the feedwater heater drainage-air preheating system," Applied Thermal Engineering, vol. 185, Feb. 2021, doi: 10.1016/j.applthermaleng.2020.116420.
- [9] M. U. Damayanti, D. Budi, U. Kuku, W. Jurusan, and T. Mesin, "Analisis Termal High Pressure Feedwater Heater di PLTU Suralaya," JURNAL TEKNIK ITS, vol. 5, no. 2, 2016.
- [10] J. Pieterse, "High Pressure Feedwater Heaters Replacement Optimisation Title: Feedwater Heaters Replacement Optimisation," 2016.
- [11] EPRI. (2002). Feedwater Heater Maintenance Guide. www.epri.com.
- [12] EPRI. (2010). 2010 Feedwater Heater Technology Conference Proceedings. <https://www.epri.com/research/products/1021491>
- [13] F. Madron, "Modeling a 3-zone Feedwater Heater," Nov. 2013, doi: 10.13140/RG.2.1.3664.7849.

- [14] ASME, "ASME PTC 12.1-2000 Closed Feedwater Heaters," 2000.
- [15] S. Kumareswaran, "Shell and tube heat exchanger design for sulfuric acid manufacturing plant," 2014, doi: 10.13140/RG.2.1.2721.6720/1.
- [16] T. L. Bergman, A. S. Lavine, F. P. Incropera, and D. P. Dewitt, *Fundamentals of Heat and Mass Transfer Seventh Edition*, 7th ed. 2011.
- [17] W. W. Chin, "The Partial Least Squares Approach to Structural Equation Modeling The Proactive Technology Project Recovery Function: A Methodological Analysis View project Research Methods View project." [Online]. Available: <https://www.researchgate.net/publication/311766005>
- [18] Incropera, F. P., & DeWitt, D. P. (2002). *Introduction to heat transfer*. John Wiley & Sons.
- [19] J. P. Holman, *Heat Transfer Tenth Edition*, 7th ed. McGraw-Hill, 2010.
- [20] Kumar, S., et al. (2016). "Performance improvement of feedwater heaters by chemical cleaning." *Journal of Chemical and Pharmaceutical Sciences*, 9(4), 3176-3180. <https://www.jchps.com/issues/v9/i4/60.pdf>
- [21] Van Maanen, P. J., and Van Nes, J. (2005). "Cleaning of feedwater heaters." *Heat Transfer Engineering*, 26(10), 26-33. <https://www.tandfonline.com/doi/abs/10.1080/01457630500246680>
- [22] Hill, K., and Pulling, D. (2012). "Minimizing feedwater heater fouling in combined cycle power plants." *GE Power & Water*. <https://www.ge.com/power/sites/default/files/products/Downloads/Minimizing%20Feedwater%20Heater%20Fouling%20in%20Combined%20Cycle%20Power%20Plants.pdf>

Citation of this Article:

Akbar Dwitama, Widayat, M.S.K Tony Suryo Utomo, Nazaruddin Sinaga, "Performance Analysis of HP Heater with Comparison of the Number of Plugging Tubes in a 400 MW Coal-Fired Power Plant" Published in *International Research Journal of Innovations in Engineering and Technology - IRJIET*, Volume 7, Issue 5, pp 1-10, May 2023. Article DOI <https://doi.org/10.47001/IRJIET/2023.705001>
