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SINTA 3

ANALYSIS OF AIR PREHEATER EFFECTIVENESS USING THE NUMBER TRANSFER UNIT (NTU) METHOD BEFORE AND AFTER OVERHAUL OF UNIT 2 OF THE WEST JAVA PALABUHAN RATU PLTU

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Abstract. The air preheater (APH) is a heat exchanger component that plays a crucial role in improving boiler combustion efficiency through the reuse of hot exhaust gases. Continuous use of the APH at the Jabar 2 Palabuhan Ratu PLTU can lead to a decline in performance, characterized by reduced heat transfer effectiveness. To restore APH performance, an overhaul was performed, including cleaning and replacing the elements. The analysis was based on actual operating data by comparing pre- and post-overhaul conditions at nearly equivalent loads using the NTU-effectiveness method, as well as calculating the effect of O_2 based air leakage. The results showed that the overhaul improved the APH's performance. Under pre-overhaul conditions with a load of 333.86 MW, the effectiveness value was 85.04%, increasing to 87.72% at a load of 329.75 MW after the overhaul. At a load of 336.98 MW, the effectiveness increased from 85.68% to 87.30% at a load of 346 MW after the overhaul. At a load of 284.33 MW, the effectiveness increased from 85.82% to 87.10% at a load of 282.99 MW after the overhaul. Furthermore, the air leakage value decreased from 13.54% to 11.47% after the overhaul.

Keywords: Air preheater, Overhaul, Effectiveness, Air leakage, NTU

Abstrak. *Air preheater (APH) merupakan komponen penukar panas yang berperan penting dalam meningkatkan efisiensi pembakaran boiler melalui pemanfaatan kembali panas gas buang. Seiring waktu operasi, penggunaan APH di PLTU Jabar 2 Palabuhan Ratu secara kontinu dapat menyebabkan penurunan kinerja yang ditandai oleh berkurangnya efektivitas perpindahan panas. Untuk mengembalikan kinerja APH, dilakukan kegiatan overhaul berupa pembersihan dan penggantian elemen. Analisis dilakukan berdasarkan data operasi aktual dengan membandingkan kondisi sebelum dan sesudah overhaul pada beban yang hampir setara menggunakan metode NTU-efektivitas, serta perhitungan pengaruh air leakage berbasis* O_2*. Hasil penelitian menunjukkan bahwa kegiatan overhaul meningkatkan kinerja APH. Pada kondisi sebelum overhaul dengan beban 333,86 MW, nilai efektivitas sebesar 85,04% meningkat menjadi 87,72% pada beban 329,75 MW setelah overhaul. Pada beban 336,98 MW, efektivitas meningkat dari 85,68% menjadi 87,30% pada beban 346 MW setelah overhaul. Pada beban 284,33 MW, efektivitas meningkat dari 85,82% menjadi 87,10% pada beban 282,99 MW setelah*

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overhaul. Selain itu, nilai air leakage mengalami penurunan dari 13,54% menjadi 11,47% setelah overhaul.

Kata kunci: *Air preheater, Overhaul, Efektivitas, Air Leakage, NTU*

1. Introduction

A steam-powered power plant (PLTU) is a type of power plant that uses steam to generate electricity [1]. The process involves converting thermal energy generated by the combustion of fossil fuels or derived from other sources into mechanical energy via steam, which is then converted into electrical energy [2].

In large scale coal fired power plants, combustion efficiency is a critical factor determining the plant's overall performance [2]. Suboptimal combustion increases fuel consumption, reduces thermal cycle efficiency, and directly contributes to higher operating costs and flue gas emissions [3]. One of the largest sources of energy loss in a power plant's boiler system stems from the heat carried by flue gases to the stack; if this heat is not utilized, it will result in a significant decrease in efficiency [4].

One component that plays a major role in improving the efficiency of a boiler's combustion system is the air preheater (APH) [5]. The APH functions by utilizing the heat from flue gases to preheat the combustion air before it enters the combustion chamber [6], thereby making the combustion process more efficient and reducing fuel consumption [4]. However, over time, APH performance can decline due to ash buildup (fouling) and air leaks in the heating elements. These conditions lead to reduced heat transfer effectiveness and boiler efficiency [2]. Therefore, periodic overhauls are necessary to clean, repair, and ensure that the equipment is operating at optimal performance [7]. Overhaul activities include cleaning deposits from the heating elements, inspecting the condition of internal components, repairing damaged or worn parts, and readjusting the sealing system to reduce the potential for air and gas leaks. In addition, inspections are also carried out on supporting systems such as bearings and lubrication systems to maintain the stability of the rotor's rotation during operation.

Various studies using a range of methods can improve the effectiveness of APH. A previous study by Purba et al. (2022) analyzed the effectiveness of APH before and after an overhaul using actual operational data. The results showed that after the overhaul, effectiveness increased by 2-4% [8]. Another study by Wardoyo et al. (2020) used the energy balance method, log mean temperature difference (LMTD), number of transfer units (NTU), and heat exchanger efficiency to evaluate the effect of air leakage on APH performance before and after an overhaul [9]. He results after the overhaul showed a reduction in air leakage from 19.32% to 11.96%, which increased the APH efficiency from 91.44% to 92.86% meaning efficiency improved by 1.42% and reduced losses by Rp. 1.069.222.68 per day due to the decrease in air leakage [9]. Such studies, based on power plant operational data, remain limited.

The UBP West Java 2 Pelabuhan Ratu Coal-Fired Power Plant is one of the coal-fired power plants critical to the Java-Madura-Bali (Jamali) power system, which has been in operation since 2013. The plant is located on Cipatuguran Beach, Jayanti Village, Pelabuhan Ratu, Sukabumi, West Java. This power plant has a total installed capacity of 1,050 MW, consisting of three generating units, each with a capacity of 350 MW. It utilizes a Ljungstrom tri-sector APH [10]. Study results indicate that the APH efficiency at the West Java 2 Pelabuhan Ratu Power Plant (based on historical data) falls within a relatively high range. For example, analyses at 50% (215 MW), 75% (270 MW), and 100% (330 MW) load levels show varying efficiency values before and after component replacement or overhauls.

After operating for approximately 12 years, the Pelabuhan Ratu Coal-Fired Power Plant is likely to experience a decline in performance. To address this decline, the plant requires periodic overhauls every 2-4 years. In July-August 2025, a comprehensive overhaul of the APH was conducted, including the cleaning of the hot, intermediate, and cold elements using a water jet method to remove deposits that could potentially reduce heat transfer. Following the cleaning, inspections and repairs were performed on the APH segment areas, radial seals, axial seals, and circumferential seals to ensure they were in good physical condition and precisely adjusted, thereby preventing gas or air leaks. Several components were replaced, including axial, radial, and circumferential seals, as well as thrust bearings and radial bearings, due to wear and deformation that could cause air leaks.

Based on the above discussion, this study will calculate the effectiveness of the APH before and after the overhaul using the NTU method, based on data from 2025, and determine the effect of air leakage on the APH. This analysis can provide a more objective evaluation of changes in the heat transfer characteristics of the APH elements, as well as the success of the overhaul in improving thermal performance and the efficiency of exhaust gas heat utilization.

2. Research Methods

The study was conducted on Air Preheater A of Unit 2 at the Palabuhan Ratu Coal-Fired Power Plant in West Java, which uses a regenerative Ljungström tri-sector air preheater [10]. The data used consisted of actual operating data for Air Preheater A of Unit 2 before and after the overhaul under relatively similar load conditions, obtained from the DCS (Distributed Control System) in the Efficiency Division and the Engineering Department at the Palabuhan Ratu West Java 2 Power Plant. This was supported by several theories and scientific journals. The load variations used during the pre-overhaul period were 333.86 MW, 336.98 MW, and 284.33 MW, while during the post-overhaul period, the loads were 329.75 MW, 346 MW, and 282.99 MW.

This study employs the NTU-Efficiency method by calculating the energy balance, gas heat capacity rate, air heat capacity rate, heat flux, Log Mean Temperature Difference (LMTD), water preheater surface area, overall heat transfer coefficient, Number of Transfer Units (NTU), heat capacity ratio, efficiency, and the effect of air leakage [8,11].

The calculation begins by determining the energy balance using the equation [5]:

$$\dot{\mathrm{Q}} = \dot{\mathrm{m}} c_p \left(\mathrm{T_o} - \mathrm{T_i}\right) \tag{1}$$

The maximum heat transfer rate is calculated using the following equation:

$$\dot{\mathrm{Q}}_{\mathrm{maks}} = \mathrm{C_{min}}\left(\mathrm{T_{hin}} - \mathrm{T_{cin}}\right) \tag{2}$$

LMTD is the logarithmic mean temperature difference between the hot fluid and the cold fluid. The equation for calculating LMTD is as follows:

$$\text{LMTD} = \frac{(T_{hin} - T_{cout}) - (T_{hout} - T_{cin})}{\ln(T_{hin} - T_{cout})/(T_{hout} - T_{cin})} \tag{3}$$

NTU is used to evaluate the performance of heat exchangers, particularly in efficiency analysis; the NTU equation is expressed as follows:

$$\text{NTU} = \frac{UA}{C_{min}} \tag{4}$$

The total heat transfer coefficient (U) can be determined using the following equation:

$$U = \frac{\dot{Q}}{A x \Delta \text{LMTD}} \tag{5}$$

The surface area of the cylindrical preheater A is given by the following formula:

The calculation of the heat capacity ratio between the cold fluid and the hot fluid

$$A = 2 \text{ x } \pi x r \,(r + h) \tag{6}$$

is expressed as:

$$C_R = \frac{C_c}{C_h} \tag{7}$$

The effectiveness of the Number Transfer Unit (NTU) method (ϵ) is calculated using the following equation:

$$(\epsilon) = \frac{1 - \exp\,[-\text{NTU}\,(1 - C_R)]}{1 - C\,\exp\,[-\text{NTU}\,(1 - C_R)]} \tag{8}$$

Air leakage is the volume or mass of combustion air that is carried from the air side to the exhaust gas side. The equation for calculating air leakage is as follows [9]:

$$\text{AL} = \frac{O_{2outlet} - O_{2inlet}}{21 - O_{2outlet}} \text{ x } 0{,}9 \text{ x } 100 \tag{9}$$

3. Results and Discussion

3.1 Operating Parameters of the Air Preheater (APH)

APH A operational parameter data was used as the basis for the system performance analysis. This data covers conditions before and after the overhaul, allowing it to be used to evaluate changes in performance. The parameters presented are variables that affect the heat transfer process and the effectiveness of the APH. The APH A parameter data before and after the overhaul is shown in Table 1

Table 1. Air preheater A data parameters before and after the overhaul

Parameters	**Notation**	**Before Overhaul**			**After Overhaul**		
Time (months)	-	**Jan**	**Apr**	**May**	**Aug**	**Sep**	**Nov**
Load (MW)	-	333.86	336.98	284.33	329.75	346	282.99
Inlet Flue Gas Temperature (°C)	T_{hin}	381.40	380.98	369.61	362.93	370.15	366.69
Outlet Flue Gas Temperature (°C)	T_{hout}	140.90	151.77	145.32	141.24	140.27	137.87
Secondary Inlet Air Temperature	T_{sain}	31.520	31.76	32.92	31.35	28.24	30.34

(°C)							
Secondary Outlet Air Temperature (°C)	T_{saout}	318.34	325.16	315.75	317.29	321.33	317.35
Primary Inlet Air Temperature (°C)	T_{pain}	41.61	42.02	42.14	39.49	37.58	39.8
Primary Outlet Air Temperature (°C)	T_{paout}	341.28	338.22	329.28	328.11	333.14	328.59
APH Inlet Temperature (°C)	T_{cin}	36.57	36.89	37.53	35.42	32.91	35.07
APH Outlet Temperature (°C)	T_{cout}	329.81	331.69	322.51	322.70	327.24	322.97
Secondary Air Flow (Ton/jam)	$\dot{m}_{sa}$	483.71	453.82	471.91	455.51	478.61	455.27
Primary Air Flow (Ton/jam)	$\dot{m}_{pa}$	478.41	490.09	491.86	505.18	427.1	500.16
Total Air Flow (Ton/jam)	$\dot{m}_{c}$	962.43	945.29	964.29	961.15	950.6	941.61
O_2 Inlet Flow (%)	O_{2inlet}	0.90	2.95	4.94	3.12	3.81	5.58
O_2 Outlet Flow (%)	$O_{2outlet}$	3.40	6.72	5.76	4.51	5.82	7.89
Diameter (m)	D	11.28	11.28	11.28	11.28	11.28	11.28
Height (m)	h	2.19	2.19	2.19	2.19	2.19	2.19
Radius (m)	r	5.64	5.64	5.64	5.64	5.64	5.64

3.2 Results of the APH Effectiveness Calculation

The results of the APH effectiveness calculations are shown in Table 2.

Table 2 Results of the Air Preheater A Efficiency Evaluation Before and After the Overhaul

Parameters	Notation	Before Overhaul			After Overhaul		
Time	**-**	**Jan-25**	**Apr-25**	**May-25**	**Agt-25**	**Sep-25**	**Nov-25**
Load (MW)	-	333.86	336.98	284.33	329.75	346	282.99
Average hot temperature (°C)	$T_{hrata-rata}$	261.15	266.38	257.47	252.09	255.21	254.26
Average cold temperature (°C)	$T_{crata-rata}$	183.19	184.29	180.02	179.06	180.07	179.02
Hot temperature (K)	T_h	534.15	539.38	530.47	525.09	528.21	525.28
Cold temperature (K)	T_c	456.19	457.29	453.02	452.06	453.07	452.02
Specific heat of gas (kJ/kg°C)	C_{ph}	1.04	1.04	1.04	1.03	1.04	1.04
Specific heat of air (kJ/kg°C)	C_{pc}	1.02	1.02	1.02	1.02	1.02	1.02
Gas flow rate (ton/jam)	$\dot{m}_h$	1,155.70	1,194.81	1,201.03	1,227.90	1,143.20	1,166.66
Heat Capacity of Gas(kJ/kg°C)	C_h	332.75	344.41	346.96	352.86	328.74	337.03
Heat Capacity of Air(kJ/kg°C)	C_c	272.90	267.79	273.07	272.29	256.76	267.87
Maximum Heat Flow Rate (kJ/s)	$\dot{Q}_{maks}$	94,104.9	92,142.2	90,680.5	89,179.2	86,588.7	88,831.7
Heat Flow Rate of Air (kJ/s)	$\dot{Q}_h$	80,026.1	78,943.1	77,820.3	78,224.8	75,570.0	77,120.3

Heat Flow Rate of Flue Gas (kJ/s)	$\dot{Q}_c$	80,0261	78,943.1	77,820.3	78,224.8	75,570.0	77,120.3
Temperature Difference-1 (°C)	ΔT_1	51.59	49.29	47.10	40.23	42.92	43.72
Temperature Difference-2 (°C)	ΔT_2	104.34	114.88	107.79	105.82	107.36	102.80
LMTD (°C)	-	74.89	77.51	73.30	67.82	70.28	69.10
Surface Area (m^2)	A	277.16	277.16	277.16	277.16	277.16	277.16
Total Heat Transfer Coefficient (W/m^2°C)	U	3.86	3.67	3.83	4.16	3.88	4.03
Number of transfer unit	NTU	3.92	3.80	3.89	4.24	4.19	4.17
Heat Capacity Ratio	C_R	0.82	0.78	0.77	0.77	0.78	0.79
Efektiveness (%)	ϵ	85.04	85.68	85.82	87.72	87.30	87.10
Avarage Air leakage (%)	$\overline{AL}$		13.54			11.48	

3.3 Analysis of Air Preheater Effectiveness

The LMTD graph plotted against power plant load before and after the overhaul is shown in Figure 1.

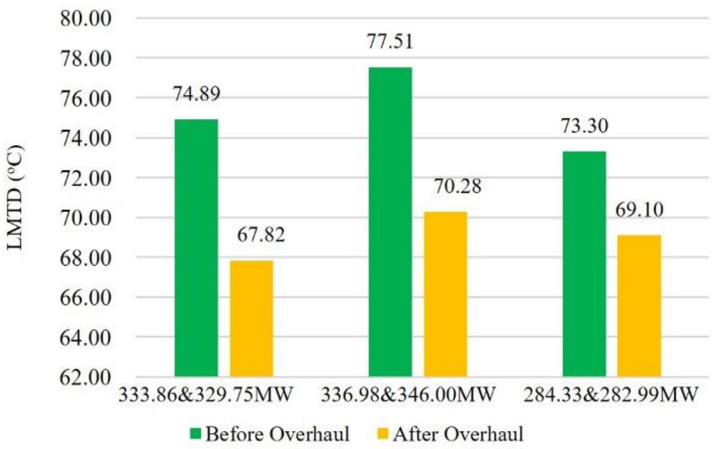

Figure 1. Graph of the log of the mean temperature difference before and after the overhaul

Based on Figure 1, the LMTD value decreased across all load variations following the overhaul. This decrease indicates that the flue gas temperature and combustion air temperature are becoming increasingly similar, suggesting that the heat transfer process is occurring more effectively. These conditions indicate that the utilization of exhaust gas heat to heat the combustion air increased following the overhaul. The graph of the total heat transfer coefficient versus plant load is shown in Figure 2.

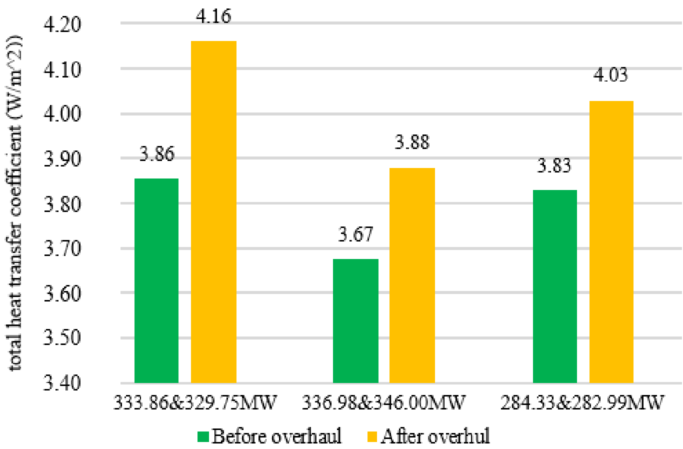

Figure 2. Variation in the Overall Heat Transfer Coefficient of Air Preheater A Before and After the Overhaul.

As shown in Figure 2, the total heat transfer coefficient (U) increased after the overhaul across all load variations. This increase indicates improved heat transfer characteristics in the air preheater due to reduced thermal resistance in the heating elements. The increase in the U value indicates that heat from the flue gas can be transferred more effectively to the combustion air, which in turn contributes to an increase in the NTU value and the efficiency of the air preheater. Figure 3 shows the NTU value as a function of load.

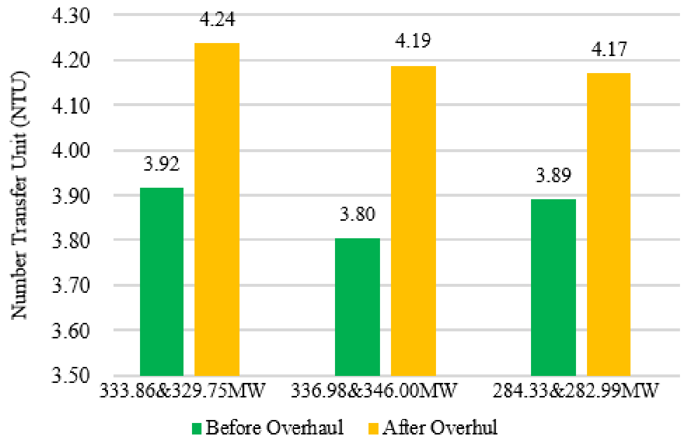

Figure 3. NTU graph before and after the overhaul

Based on Figure 3, the NTU value increased after the overhaul across all load variations. This increase indicates that the heat transfer capacity of the air preheater improved due to an increase in the total heat transfer capacity (UA). According to the ε-NTU method, an increase in the NTU value indicates improved heat transfer efficiency, allowing flue gas heat to be utilized more effectively to heat the combustion air. Figure 4 shows the APH efficiency values as a function of plant load.

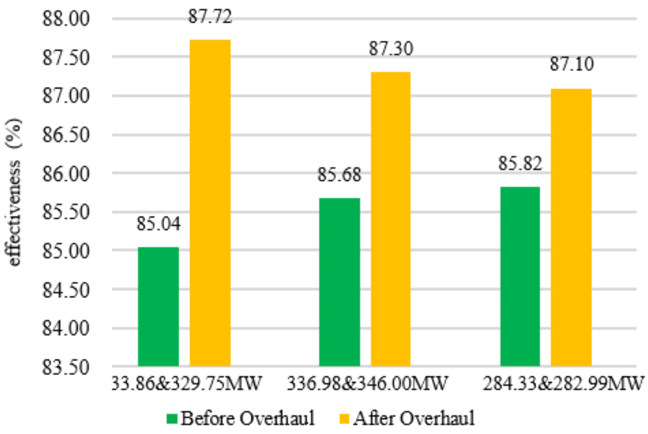

Figure 4. Graph showing the effectiveness of APH A before and after the overhaul

Based on Figure 4, the efficiency of the air preheater increased across all load variations following the overhaul. This increase in efficiency indicates that the utilization of flue gas heat to heat the combustion air has become more optimal. This is consistent with the increase in the NTU value, which indicates improved heat transfer due to reduced thermal resistance in the heating elements and decreased air leakage following the overhaul. The effects of the overhaul on air leakage and efficiency are shown in Figure 5.

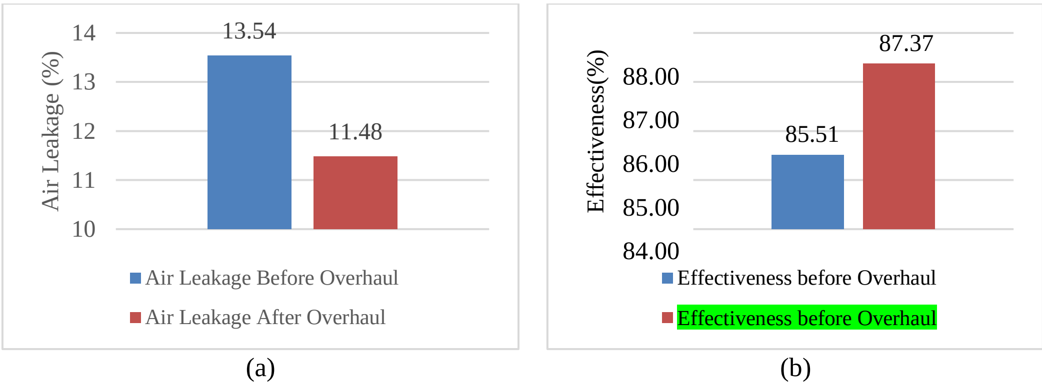

Figure 5. (a)Air leakage before and after the overhaul. (b) Effectiveness before and after the overhaul

The average water leakage rate decreased from 13.54% to 11.48% following the overhaul, accompanied by an increase in average efficiency from 85.51% to 87.37%. These results indicate that improvements to the sealing system during the overhaul contributed to the improved thermal performance of the air preheater.

4. Conclusion

The analysis results show that the overhaul improved the APH's performance across all load variations. At a load of 333.86 MW before the overhaul and 329.75 MW after the overhaul, efficiency increased from 85.04% to 87.72% (an increase of 2.68%). At a load of 336.98 MW before the overhaul and 346.00 MW after the overhaul, efficiency increased from 85.68% to 87.30% (an increase of 1.62%). Meanwhile, at a load of 284.33 MW before the overhaul and 282.99 MW after the overhaul, efficiency increased from 85.82% to 87.10% (an increase of 1.28%). This increase in efficiency was supported by improved heat transfer characteristics following the overhaul, as well as a reduction in water leakage from 13.54% to 11.47% due to improvements in the sealing system. These results indicate that the overhaul was able to optimize the utilization of flue gas heat to preheat combustion air.

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