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# Performance Evaluation of Leakage Cross-Flow Heat Exchanger in Coal-Fired Power Plant.

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**Abstract**

This research work is to study the performance of the leakage cross-flow heat exchanger of 300 MW coal-fired power plant. Normally, this equipment exchanges heat between the hot flue gas and the inlet combustion air, to ensure the coal is dried before transported to the furnace which operated under high content of fly ash. The test was done with full ASME PTC 4.3 field test to provide final verification of performance. The leakage values of selected cross-flow heat exchanger were 6.31, 7.37, and 7.65 % respectively where power plant was run at guaranteed turbine generator capacity 100, 80, and 60 % respectively. At this conditions, cross-flow heat exchanger gas side efficiency was found in low level i.e. 66.79, 65.40, and 62.07 % respectively, X-ratio were 0.924, 0.884, and 0.793 respectively. The air heater leakage and particulate matter have an effect on the performance of the cross-flow heat exchanger and would trend to poor condition.

**Keywords**: Heat exchanger, leakage, particulate, performance.

## 1. Introduction

Heat exchanger is a device that is used to transfer thermal energy from higher temperature heat source to lower temperature heat sink. There are many types of heat exchanger applicable to the recovery of waste heat such as shell-and-tube heat exchanger, plate-type heat exchanger, and cross-flow heat exchanger. The cross flow type is very popular due to low cost and easy to clean and clear.

In Mae Moh coal-fired power plants, there are many types of cross-flow heat exchangers i.e. primary air heater, economizer etc. Normally, the heat exchanger named primary air heater is recovered heat from the high temperature flue gas to warm up the combustion air. Furthermore, this heater is operated under the high particulate condition which are fly ash from the combustion process and trend to decreased its performance.

Unfortunately, there is lack of data about the performance decreasing due to this condition. Therefore, the objective of this research work is to investigate the performance of the cross-flow heat exchanger named primary air heater of Mae Moh coal-fired power plant under leakage and high particulate conditions.

## 2. Performance Data

In this work, the primary air heater of 300 MW in Mae Moh coal-fired power plant, unit 10, no.2 is selected for investigating. The tested data were recorded every 15 minutes, 3 hours, during generation output were kept at 300, 240, and 180 MW respectively where operated with coal fuel. The in-line tube arrangements and dimensions of cross-flow heat exchanger are shown on figure 1 and table 1 respectively.

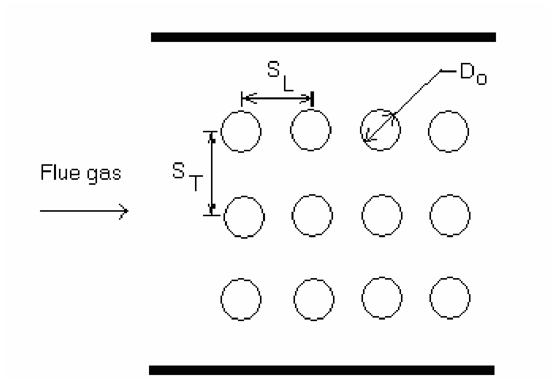


Figure 1 In-line tube arrangements of cross-flow heat exchanger.

Table 1 Dimension of tested cross-flow heat exchanger.

| Type | Cross flow, 1 flue gas pass and 3 combustion air pass |
|---|---|
| Number of tubes | 1,540 |
| Number of tube rows | 28 |
| Tube arrangement | Inline |
| Transverse tube pitch | 1.3386 $D_o$ |
| Longitudinal tube pitch | 1.3386 $D_o$ |
| Tube diameter | 0.0762 m |
| Tube length | 9.017 m/pass |

The collected data are shown in table 2 and all symbols were listed in nomenclature item.

Table 2 The collected data.

| Categories | Values | | |
|---|---|---|---|
| Power generation (MW) | 300 | 240 | 180 |
| GTC (%) | 100 | 80 | 60 |
| Coal flow (kg/s) | 73.571 | 60.158 | 46.265 |
| Total air flow to boiler (kg/s) | 335.13 | 301.49 | 266.06 |
| Barometric pressure (mbar) | 972.51 | 969.30 | 974.15 |
| Ambient air temp. (ºC) | 31.19 | 35.25 | 32.05 |
| $CO_{2,gi}$ (%) | 16.80 | 14.93 | 13.53 |
| $CO_{2,go}$ (%) | 15.70 | 13.80 | 12.47 |
| Air leakage (%) | 6.31 | 7.37 | 7.65 |
| Air inlet temp. (ºC) | 58.16 | 61.40 | 61.92 |
| Air outlet temp. (ºC) | 327.16 | 317.47 | 325.94 |
| Gas inlet temp. (ºC) | 430.48 | 407.52 | 399.34 |
| Gas outlet temp. (ºC) | 174.55 | 173.01 | 180.88 |
| Gas flow through PAH2 (kg/s) | 64.58 | 62.735 | 46.42 |
| Air flow through PAH2 (kg/s) | 64.45 | 60.44 | 41.94 |
| Specific heat of air through PAH (kJ/kg ºC) | 1.023 | 1.023 | 1.023 |
| Specific heat of gas through PAH (kJ/kg ºC) | 1.0551 | 1.0517 | 1.0517 |

**3. Data Reduction**

The approximation of percentage of air leakage, $L_a$, may be obtained as equation (1).

$$L_a = \frac{CO_{2,gi} - CO_{2,go}}{CO_{2,go}} \times 90 \tag{1}$$

The factor, 90, is recommended by [1], will result in percentage leakage figures that are very close to leakage determined on a weight basis.

Calculated gas temperature outlet of air heater for no leakage, $T_{go,NL}$, [1], can be defined as equation (2).

$$T_{go,NL} = \frac{L_a c_{p,a}(T_{go} - T_{ai})}{100\, c_{p,g}} + T_{go} \tag{2}$$

X-ratio is the ratio of heat capacity of the air passing through the air heater to the heat capacity of gas passing through the air heater, $XR$, [1], can be calculated as equation (3).

$$XR = \frac{\dot{m}_a c_{p,a}}{\dot{m}_g c_{p,g}} = \frac{T_{gi} - T_{go,NL}}{T_{ao} - T_{ai}} \tag{3}$$

Gas side efficiency, $\eta_g$ is the ratio of gas temperature drop, corrected for no air leakage, to temperature head, [1] as equation (4).

$$\eta_g = \frac{T_{gi} - T_{go,NL}}{T_{gi} - T_{ai}} \times 100 \tag{4}$$

where temperature head is the gas inlet temperature minus air inlet temperature.

In this experiment, hot gas flowing outside the tube bank transfers heat to the inside tube air and the heat transfer rate ($\dot{Q}$) can be calculated as equation (5) and (6).

$$\dot{Q} = \dot{m}_a c_{p,a}(T_{ao} - T_{ai}) \tag{5}$$

$$\dot{Q} = \dot{m}_g c_{p,g}(T_{gi} - T_{go}) \tag{6}$$

The heat transfer rate can be calculated in the form of log mean temperature difference method as equation (7).

$$\dot{Q} = UAF\Delta T_{lm} \tag{7}$$

The overall heat transfer coefficient area of the heat exchanger can be evaluated in the term of thermal resistance as equation (8).

$$\frac{1}{UA} = \frac{1}{h_o A_o} + \frac{\ln(D_o / D_i)}{2\pi k_t L} + \frac{1}{h_i A_i}. \tag{8}$$

The tube side heat transfer coefficient can be estimated by Dittus-Boelter equation, [2], in the term of Nusselt number as equation (9).

$$Nu = 0.023\, Re_{Di}^{\,0.8}\, Pr^{n} \tag{9}$$

Note that Nusselt number, Reynolds number and Prandtl number in this work are defined as equation (10), (11), and (12).

$$Nu = \frac{h_i D_i}{k_a} \tag{10}$$

$$\mathrm{Re}_{D,i} = \frac{4\dot{m}_a}{\pi D_i \mu} \tag{11}$$

$$\mathrm{Pr} = \frac{c_{p,a}\, \mu_a}{k_a} \tag{12}$$

For the flue gas side, Zhukauskas's equation, [3], is adapted for evaluating the heat transfer coefficient, $h_o$. This equation is the functions of Reynolds number and Prandtl number as equation (13).

$$h_o = 0.27 \frac{k_f}{D_o} \mathrm{Re}_{D,o}{}^{0.63} \mathrm{Pr}^{0.36} \tag{13}$$

The flue gas side Reynolds number is defined as equation (14).

$$Re_{D,o} = \frac{\rho_f \ V_{max} \ D_o}{\mu_f} \tag{14}$$

where

$$V_{\max} = \frac{S_T}{S_T - D_o} V \tag{15}$$

**4. Results and Discussion**

The selected cross-flow heat exchanger of coal-fired power plant was tested during power plant gross generation were 300, 240, and 180 MW respectively.

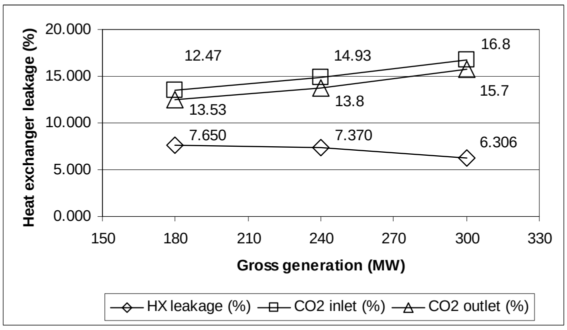


Figure 2 Gross generation and heat exchanger leakage.

Figure 2, the percentage of $CO_2$ gas entering and leaving air heater have decreased while power plant gross generations were decreased, but the percentage of heat exchanger leakage have increased, 6.31, 7.37, and 7.65% while power plant gross generations were decreased, 300, 240, and 180 MW respectively.

Figure 3, the measured air and gas temperatures at inlet and outlet of selected air heater have displayed.

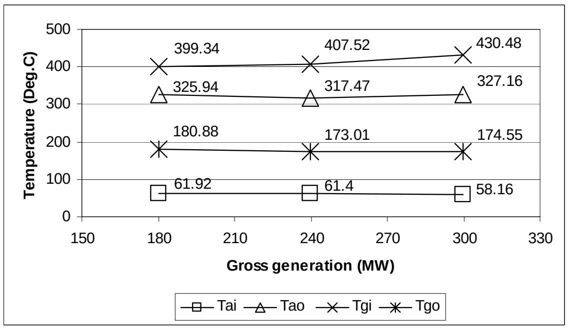


Figure 3 Temperatures of air and gas entering and leaving the air heater.

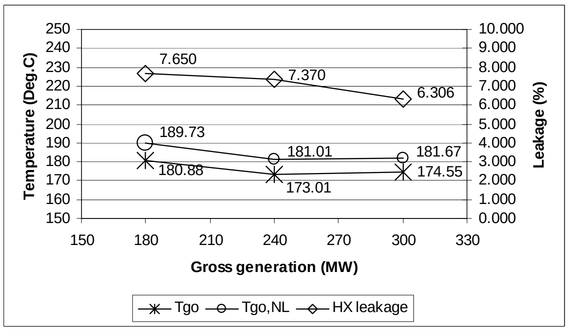


Figure 4 Air heater leakage and outlet gas temperature.

Figure 4, calculated gas temperature leaving air heater for no leakage was higher than measured gas temperature leaving air heater.

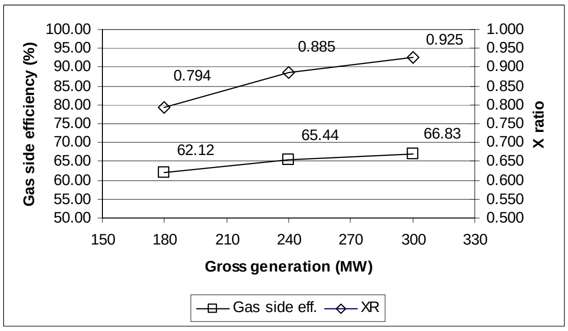


Figure 5 Gas side efficiency and X ratio compared with gross generation.

Figure 5, at power plant gross generations 300, 240, and 180 MW, the gas side efficiency were 66.83, 65.44, and 62.12 % respectively. At the same power generations, X ratio were 0.925, 0.885, and 0.794 respectively. At 300 MW gross generation, the gas side efficiency and X ratio were the highest of each series.

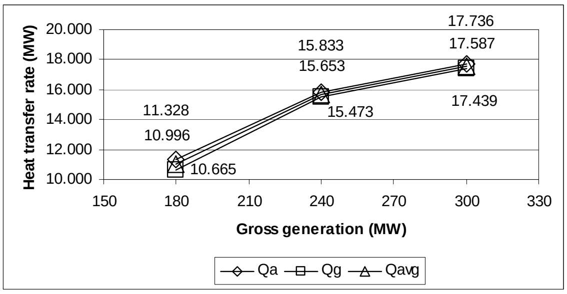


Figure 6 Heat transfer rate of tested cross-flow heat exchanger.

Figure 6, shows heat transfer rate of tested cross-flow heat exchanger. It was found that the gas side heat transfer rate differs from air side approximately 1.7-6.2% and the heat transfer rate average were 17.587, 15.653, and 10.996 MW when gross generations were 300, 240, and 180 MW respectively.

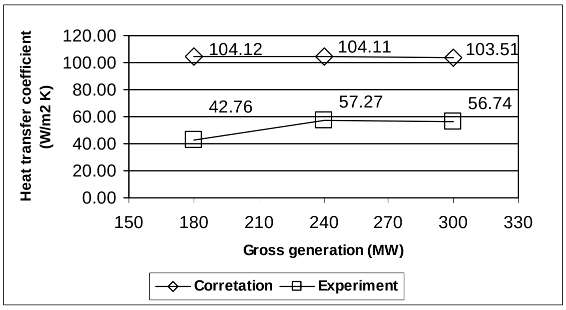


Figure 7 Heat transfer coefficient.

Figure 7, at gross generation 300, 240, 180 MW, the heat transfer coefficients which calculated from Zhukauskas's equation, [3] were 103.51, 104.11, and 104.12 W/m$^2$ K, this line remain constant, but from air leakage and under particulate conditions, the heat transfer coefficient were found very low values i.e. 56.74, 57.27, and 42.76 W/m$^2$ K respectively. The main factors of the very low heat transfer coefficient problem were occurred due to air in leakage. Additional, Refer to [5], at gross power generation 250-300 MW, the heat transfer coefficients which tested under particulate conditions and no leakage were approximately 80.49-88.34 W/m$^2$ K. It can be concluded that particulate conditions and leakage affecting heat transfer coefficients quite big, especially the leakage.

**5. Conclusion**

5.1 The selected heat exchanger was leaked at 6.31, 7.37, and 7.65 % while power plant gross generations were 300, 240, and 180 MW respectively.

5.2 The air heater leakage and particulate matter have an effect on the performance of the cross-flow heat exchanger. At existing leakage conditions, the heat transfer coefficients from experiment under leakage and particulate conditions were lower than heat transfer coefficients from Zhukauskas's equation quite big.

5.3. At guarantee turbine generator capacity 100, 80, and 60 %, the X-ratios were 0.924, 0.884, and 0.793 respectively.

5.4 At gross generations 300, 240, and 180 MW, the tested cross-flow heat exchanger gas side efficiency was found in low level i.e. 66.79, 65.40, and 62.07 % respectively. Unfortunately, the conditions of selected cross-flow heat exchanger would tend to poor condition such as leakage, low gas side efficiency, air outlet temperatures were lower than designed values etc. Therefore, it is recommended to investigate in detail and solve an existing problems.

**Acknowledgement**

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**Nomenclature**

| | |
|---|---|
| $A$ | area (m$^2$) |
| $c_p$ | specific heat at constant pressure (J/kg K) |
| $c_{p,a}$ | specific heat of air at constant pressure (J/kg K) |
| $c_{p,g}$ | specific heat of gas at constant pressure (J/kg K) |
| $CO_{2,gi}$ | percent by volume of dry $CO_2$ gas at air heater inlet. (%) |
| $CO_{2,go}$ | percent by volume of dry $CO_2$ gas at air heater outlet. (%) |
| $D$ | diameter (m) |
| GTC | guaranteed turbine generator capacity (%) |
| $h$ | heat transfer coefficient (W/m$^2$ K) |
| $k$ | thermal conductivity (W/m K) |

| | |
|---|---|
| $L$ | length (m) |
| $L_a$ | air leakage (%) |
| $\dot{m}$ | mass flow rate (kg/s) |
| $Nu$ | Nusselt number |
| $p$ | pressure (N/m$^2$) |
| $Pr$ | Prandtl number |
| $\dot{Q}$ | heat transfer rate (W) |
| $Re_D$ | Reynolds number |
| $S_t$ | transverse tube pitch (m) |
| $S_l$ | longitudinal tube pitch (m) |
| $T$ | temperature (°C) |
| $U$ | overall heat transfer coefficient (W/m$^2$K) |
| $V$ | velocity (m/s) |

Greek symbol

| | |
|---|---|
| $\mu$ | Dynamic viscosity (Pas) |
| $\rho$ | Density (kg/m$^3$) |

Subscript

| | |
|---|---|
| $a$ | air side |
| $f$ | flue gas side |
| $g$ | gas side |
| $i$ | Inner (Air side) or inlet |
| max | Maximum |
| $o$ | Outer (Flue gas side) |
| $t$ | Tube |