Performance Evaluation of Cross-Flow Heat Exchanger in Coal-Fired Power Plant under Particulate Condition

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Abstract

This research work is to study the performance of the cross-flow heat exchanger of 300 MW Mae Moh coal-fire power plant. Normally, this equipment exchanges heat between the hot flue gas and the inlet combustion air which operated under high content of fly ash and it brings to get lower heat transfer performance. Unfortunately, from the previous work, there is no more data about the heat transfer degradation of heat exchanger due to the high particulate condition. From this study, it was found that the flue gas side heat transfer coefficient was lower than that of Zhukauskas's model approximately 20.0 - 30.1%. Therefore, the new empirical correlation for predicting the heat transfer coefficient of this cross-flow heat exchanger was also developed in this work and it was found that the developed models can predict the experimental data quite well.

1. Introduction

A 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 suitable for recovering heat from high temperature flue gas.

In Mae Moh coal-fired power plants, there are many type of cross-flow heat exchanger especially the primary air heater. This heat exchanger is recovered heat from the high temperature flue gas to warm up the combustion air. Figure 1 shows the schematic diagram of the power plant including the primary air heater. Normally, 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 known as primary air heater of Mae Moh power plant under high particulate condition. Moreover, the empirical model is developed for predicting the performance of this equipment.

2. Performance Data

In this work, the primary air heater of 300 MW Mae Moh coal-fired power plant, unit 12 is selected for investigating. The test data were recorded 12 times, every hour, during generation output between 250-300 MW, operated with coal fuel. The collected data and the dimension of this heat exchanger is shown in table 1 and 2 respectively. The in-line tube arrangement of primary air heater is shown on figure 2.

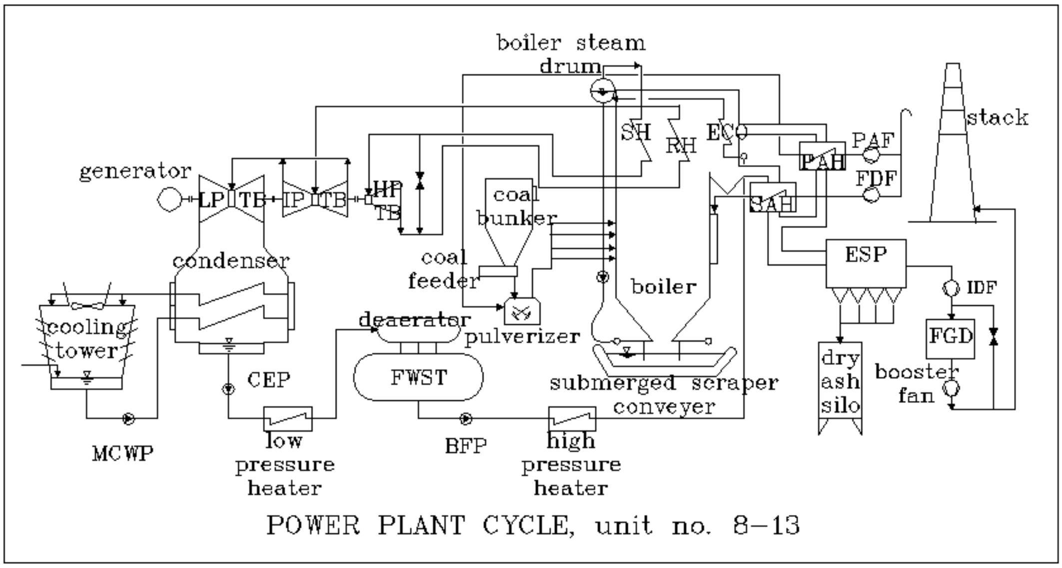

Figure 1 Schematic diagram of Mae Moh power plant

Table 1 Performance data of the primary air heater

Time (h)	Load (MW)	coal flow (t/h)	Air flow (kg/s)	T_{hi} (^{o}C)	T_{ho} (^{o}C)	T_{ci} (^{o}C)	T_{co} (^{o}C)
1	300.52	287.92	336.13	413.27	160.31	49.63	310.66
2	300.47	286.40	334.48	413.59	158.76	51.33	308.95
3	269.69	251.50	304.00	403.87	156.64	51.73	306.41
4	250.60	231.27	299.29	398.37	156.08	47.93	303.10
5	250.38	227.87	300.36	400.95	156.72	47.15	304.80
6	287.46	265.63	326.93	411.05	159.37	48.00	308.49
7	299.44	278.08	335.99	417.97	162.90	46.98	315.15
8	296.55	278.46	334.16	419.59	164.03	45.88	318.02
9	298.42	282.35	335.72	421.01	164.75	45.25	319.36
10	301.40	286.45	334.61	423.31	164.62	45.52	320.28
11	300.87	284.55	332.56	423.28	164.06	45.92	319.93
12	299.94	283.53	331.45	417.74	163.82	46.15	318.16

Table 2 Dimension of primary air heater

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
Longitudinal tube pitch	1.3386
Tube diameter	0.0762 m
Tube length	9.017 m/pass

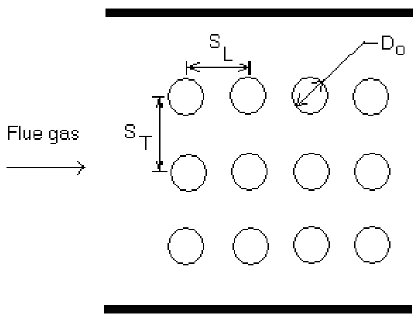

Figure 2 In-line tube arrangements of primary air heater

3. Data Reduction

In this experiment, hot gas flowing outside the tube bank transfers heat to the inside tube air and the heat transfer rate (Q) can be calculated as

$$Q = \dot{m}_a c_{pa} (T_{ao} - T_{ai}), \quad (1)$$

$$Q = \dot{m}_g c_{pg} (T_{gi} - T_{go}). \quad (2)$$

The heat transfer rate can be calculated in the form of log mean temperature difference method as

$$Q = UAF\Delta T_{lm}. \quad (3)$$

The overall heat transfer coefficient area of the heat exchanger can be evaluated in the term of thermal resistance as

$$\frac{1}{UA} = \frac{1}{h_o A_o} + \frac{\ln(D_o / D_i)}{2\pi k_t L} + \frac{1}{h_i A_i}. \quad (4)$$

The tube side heat transfer coefficient can be estimated by Dittus-Boelter equation [1] in the term of Nusselt number as

$$Nu = 0.023\, Re_{Di}^{0.8}\, Pr^n. \quad (5)$$

Note that Nusselt number, Reynolds number and Prandtl number in this work are defined as

$$Nu = \frac{h_i D_i}{k_a}, \quad (6)$$

$$\mathrm{Re}_{D,i} = \frac{4\dot{m}_a}{\pi D_i \mu}, \quad (7)$$

$$\mathrm{Pr} = \frac{c_{pa} \mu_a}{k_a}. \quad (8)$$

For the flue gas side, Zhukauskas's equation [2] is adapted for evaluating the heat transfer coefficient (h_o). This equation is the functions of Reynolds number and Prandtl number as

$$h_o = 0.27 \frac{k_f}{D_o} Re_{D,o}^{0.63}\, Pr^{0.36}. \quad (9)$$

Note that the flue gas side Reynolds number is defined as

$$Re_{D,o} = \frac{\rho_f V_{max} D_o}{\mu_f}, \quad (10)$$

where

$$V_{\max} = \frac{S_T}{S_T - D_o} V. \quad (11)$$

4. Results and Discussion

Figure 3 shows the power plant load which varied between 250-300 MW.

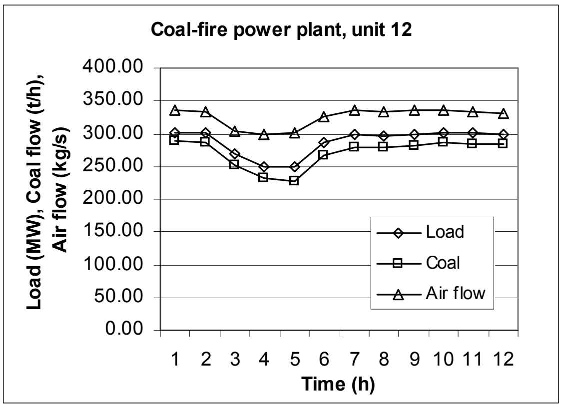

Figure 3 Power plant load

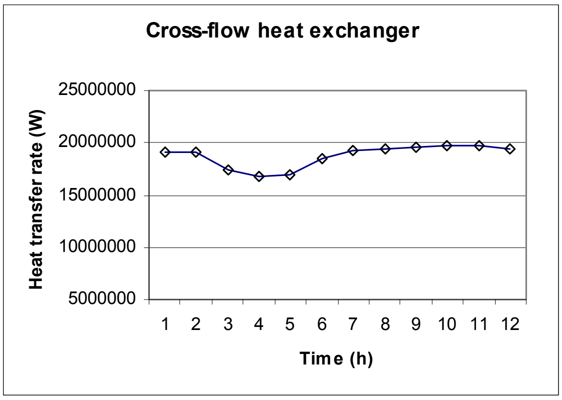

Figure 4 Heat transfer rate of primary air heater

Figure 4 shows the heat transfer rate of primary air heater. It was found that the heat transfer rate is parallel with power plant load.

Figure 5 shows the heat transfer coefficient from the experiment, It was found that the heat transfer coefficient was nearly constant and lower than that value calculated from Zhukauskas's equation approximately 20.0 – 30.1 %. This result may be come from the effect of particulate matter (fly ash). Actually, Zhukauskas's equation was selected for calculating the sizing of heat exchanger. However, this correlation agrees well with the clean air condition. Therefore, the application of this equation for evaluating the sizing of heat exchanger operated under high particulate condition, may has some error. To avoid the mistaken, the new correlation is developed for evaluating the heat transfer coefficient of the primary air heater. Equation 12 shows the detail of this correlation which works well if applying for this cross-flow heat exchanger where 0.043< k <0.0451, 36900 < Re_D < 36956, and 0.683 < Pr < 0.684 .

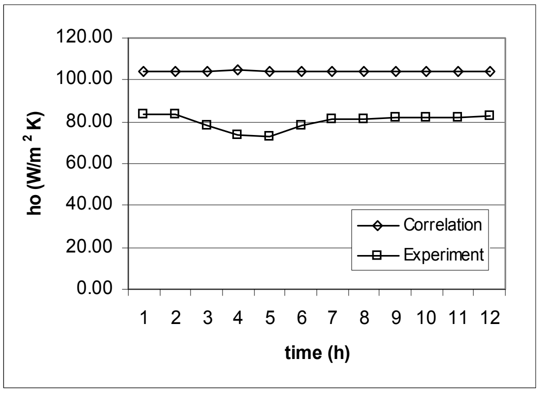

Figure 5 Heat transfer coefficient of primary air heater

$$h = 5.235 \times 10^{-8} \left(\frac{k}{D}\right)^{9.8958} \left(\mathrm{Re}_D\right)^{2.5683} \mathrm{Pr}^{1.5292} \tag{12}$$

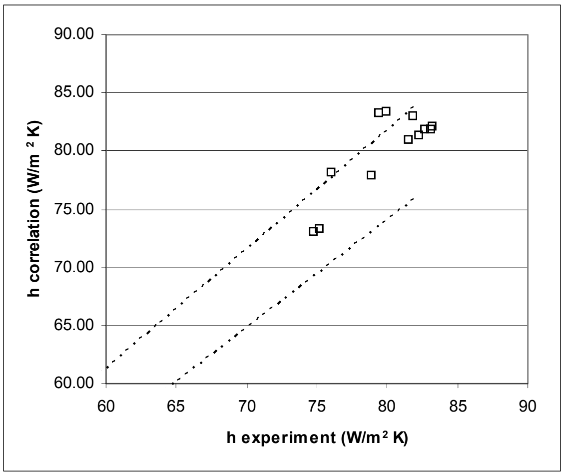

Figure 6 The comparison of the new model and the experimental data

Figure 6 shows the comparison of the developed correlation and the experimental data. The lines which shown on the figure, indicate the deviation from the average value +5% and -5%. It was found that the new correlation can predict the experimental quite well.

5. Conclusion

1. The particulate matter has an effect on the performance of the cross-flow heat exchanger.
2. Zhukauskas's equation can predicted approximately 20.0 – 30.1 % higher than that of the experimental value.
3. The new model can predict the data quite well.

6. Acknowledgement

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Reference

[1] Hewitt, G.F., Shires, G.L. and Bott, T.R. (1994), Process Heat Transfer, Boca Raton, CRC Press, 1042.

[2[Incropera, F.P. and Dewitt, D.P. (2002), Introduction to heat transfer, 4th edition, John Wiley & Sons Inc., USA.

[3] Shah, R.K., Sekulic, D.P. (2003), Fundamentals of heat exchanger design, John Wiley & Sons Inc., CANADA.

Nomenclature

A	Area (m^2)
c_p	Specific heat (J/kg K)
D	Diameter (m)
h	Heat transfer coefficient (W/m^2 K)
k	Thermal conductivity (W/m K)
L	Length (m)
$\dot{m}$	Mass flow rate (kg/s)
Nu	Nusselt number
P	Pressure (N/m^2)
Pr	Prandtl number
Q	Heat transfer rate (W)
Re_D	Reynolds number
S_t	Transverse tube pitch (m)
S_l	Longitudinal tube pitch (m)
T	Temperature (^{o}C)
U	Overall heat transfer coefficient (W/m^2K)
V	Velocity (m/s)

Greek symbol

μ	Dynamic viscosity (Pas)
ρ	Density (kg/m^3)

Subscript

a	Air side
f	Flue gas side
i	Inner (Air side)
$\max$	Maximum
o	Outer (Flue gas side)
t	Tube