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Analysis of Heat Transfer on the Heat Exchanger of Furnace Boiler Circulating Fluidizing Bed in the Power Plant

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ABSTRACT: *The electric power system consists the generation and distribution. One type of power plant is a Steam Power Plant. The main components in a power plant are Boilers, Steam Turbines, Condensers, and synchronous Generators. The heat transfer that occurs in the Heat Exchanger in the Furnace Boiler Circulating Fluidizing Bed (CFB) is conducted by Conduction, Convection, and Radiation. The purpose of this study is to calculate and compare the value of the heat transfer coefficient and it calculated the amount of heat absorbed during the research process, then compared with the actual value during the commissioning process on the Heat Exchanger in Furnace Boilers (Wall tube or HE_1, Evaporator or HE_2, and Platen Superheater or HE_3). Data collection is done by the observation method; then, the data is processed to calculate the value of the heat transfer coefficient and the amount of heat absorbed. From the research results, the computed value for the heat transfer coefficient on the actual HE_1 and commissioning was 0.598 $W/m^2\ ^0C$, on the actual HE_2 and commissioning was 0.829 $W/m^{20}C$, the actual HE_3 was 0.779 $W/m^{20}C$ and the commissioning was 0.8 $W/m^{20}C$. The amount of heat absorbed in actual HE_1 was 88.515 KJ/Kg and Commissioning was 11.99 KJ/Kg, on Actual HE_2 was 1.73 KJ/Kg and commissioning was 1.44 KJ/Kg, then on actual HE_3 amounted 271.06 KJ/Kg and commissioning amounted 72.82 KJ/Kg.*

KEYWORDS: *Furnace Boiler, Heat Exchanger, Heat Coefficient, Heat Absorbed, Heat Transfer.*

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I. INTRODUCTION

Energy is an essential thing in human life, and energy is divided into various forms in the universe. A steam power plant is the main thing that must be equipped with multiple leading types of equipment, such as a boiler, turbine, and generator[1]. The use of boilers in a steam power system is a must-have. Each Boiler used in a steam power plant has a different structure and supporting components, this is because the use of boilers is adjusted to the load generated and the amount of coal carbon used as the primary fuel in the combustion process[2].

The heat transfer in a circulating fluidized bed boiler system is influenced by several main factors, such as fuel quality, combustion chamber temperature, the shape of the combustion chamber, and so on[3], [4].

Combustion at CFB has less air pollution produced, compared to combustion at boilers other than CFB type. CFB has advantages in the type of coal used because it can use the kind of coal that is low in calories and produces good efficiency[5].

The development of a fluidized bed boiler (CFB) today is different from the model in the past[6]. At present, the development of models emphasizes that the absorption of heat is produced by furnaces, not just the mechanism of heat transfer of radiation and convection. The model which was created in the present condition is done by adding specific components on the inside of the boiler to increase efficiency and economic optimization in the process of heat absorption was generated by the furnace[3]. One way to develop a fluidized bed boiler (CFB) is by adding a Heat Exchanger component to the inside of the boiler. Based on the theory, several advantages are using a Heat Exchanger in a fluidized bed boiler (CFB) system as follows[5]:

(1) Solids through the Fluidized Boiler Heat Exchanger (FBHE) can be regulated through the available valves, which are used to control heat production during boiler operation. Therefore, bursts of water are not needed, so that boiler efficiency increases.
(2) The function of the Fluidized Bed Heat Exchanger (FBS) can control the heat in the combustion chamber and the temperature distribution in the boiler.

(3) Fluidized Bed Heat Exchanger (FBHE) can flexibly regulate the bed temperature inside of boiler by setting the combustion in the combustion chamber.
(4) Fluidized Bed Heat Exchanger (FBHE) regulates the flexibility of the temperature bed in the boiler, for varying boiler load capacities.

The technology and capacity of fluidized bed boilers (cfb) which was applied today is an increase (fig. 1). Currently, under the development and construction of more than 500 units of fluidized bed boilers (cfb) is worldwide. The most significant capacity building is 500 MWe currently underway in Gujarat, India, and other locations with capacities are reaching 600 MWe[7].

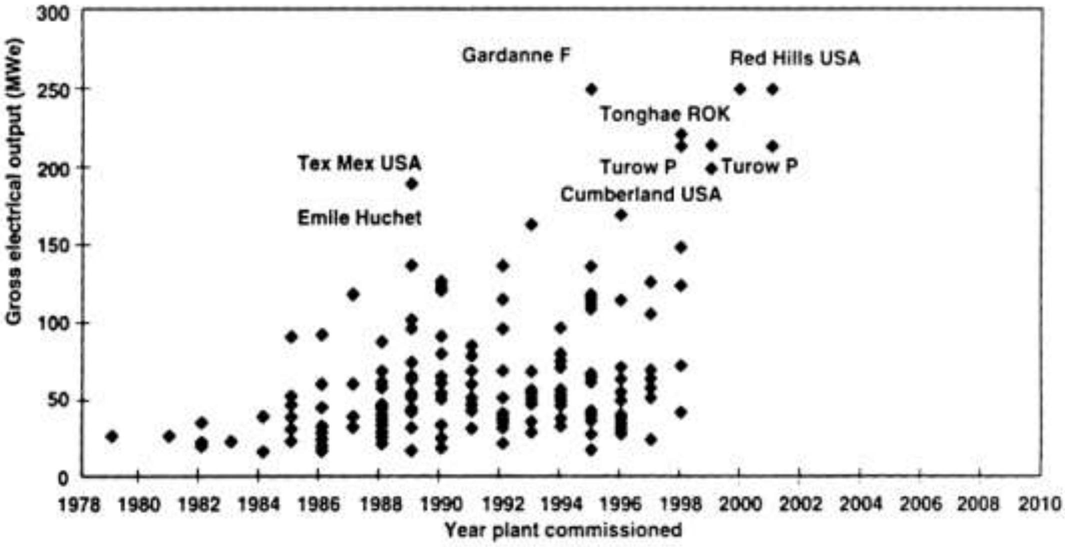

Fig. 1. The growth of the gross electrical output of CFB boilers[7]

I.1 Coal Fuel

Combustion in a fluidized bed boiler (cfb) gives a good combustion value, even though the value and quality of the fuel which was used are not good[8]. The quality of combustion results in the fluidized bed boiler is also influenced by the design of a good furnace and it is equipped with a fluidized bed heat exchanger in the boiler unit (figure 2)[7].

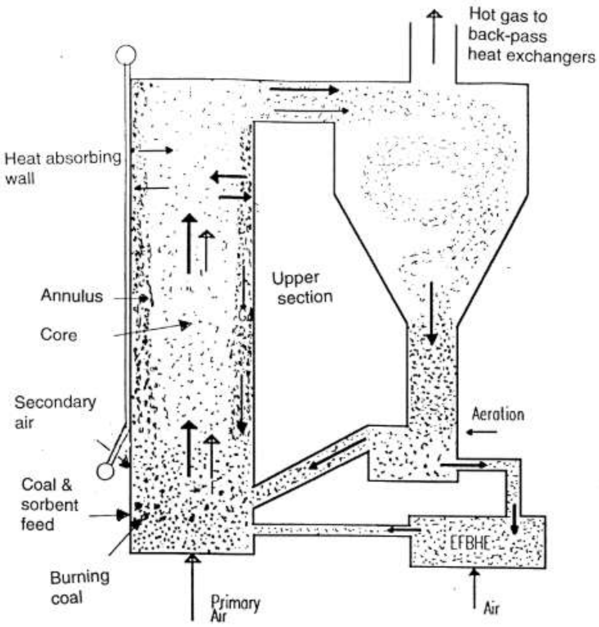

Fig. 2. Schematic of a CFB boiler furnace[7]

I.2 Heat Transfer Process

The process of heat transfer in a fluidized bed boiler (cfb) occurs in the mode of heat transfer by convection and radiation which takes place simultaneously, but the process of calculation and assessment can be done separately[9].

a. Convection

Convection heat transfer in the fluidized bed boiler (cfb) occurs due to the volumetric heat capacity that is much higher than the gas in the boiler, so the heat transfer that occurs will increase at higher concentrations[9], [10].

The volume fraction of particles in a fluidized bed boiler (cfb) is about three times the average of the cross-sectional area. The volume fraction of a particle in a wall is proportional to the volume fraction in the boiler core; thereby affecting the heat transfer is through the particle.

b. Radiation

Radiation heat transfer in a fluidized bed boiler (cfb) occurs due to several factors, including the optical wall layer and wall thickness[11]. Assuming that the cross-sectional area of the boiler equals the geometric cross-sectional area of the particles inside the boiler, the optical thickness can be calculated as[9], [11]:

$$\tau = \int_0^x 3\phi/2d_p dx$$

The heat generated in the fluidized bed boiler (cfb) varies for several positions in the boiler. The temperature around the center of the boiler is around 850 ^{0}C and the particle temperature close to the boiler wall is around 200 ^{0}C[12]. The chosen emissivity is around 0.8 which is the combined emissivity of particles and gases[9].

$$\alpha_r = \left({}^1/_{\varepsilon_s} + {}^1/_{\varepsilon_w} - 1\right)^{-1} \alpha(T_s^2 + T_w^2)(T_s + T_w)$$

$$\varepsilon_s = 1 - (1 - \varepsilon_{pc})(1 - \varepsilon_g) = \varepsilon_{pc} + \varepsilon_g - \varepsilon_{pc}\varepsilon_g$$

Because the emissivity of particles is scattering, the relationship between particles gives the following results[9], [13], [14].

$$\varepsilon_{pc} = \varepsilon_p^{0.31}$$

The combustion gas emissivity in a large combustion condition gives a value of 0.25 which is combustion emissivity in a fluidized bed boiler (cfb) of 0.6, in Eq (4). The cloud emissivity of the particles becomes 0.85, in Eq. (3), then a total suspension emissivity for the gas particles in the boiler is obtained 0.88. The limit of emissivity validity for radiant heat transfer is given by the following equation:

$$\eta_r = {}^{\alpha_r}/_{\alpha_{r,max}}$$

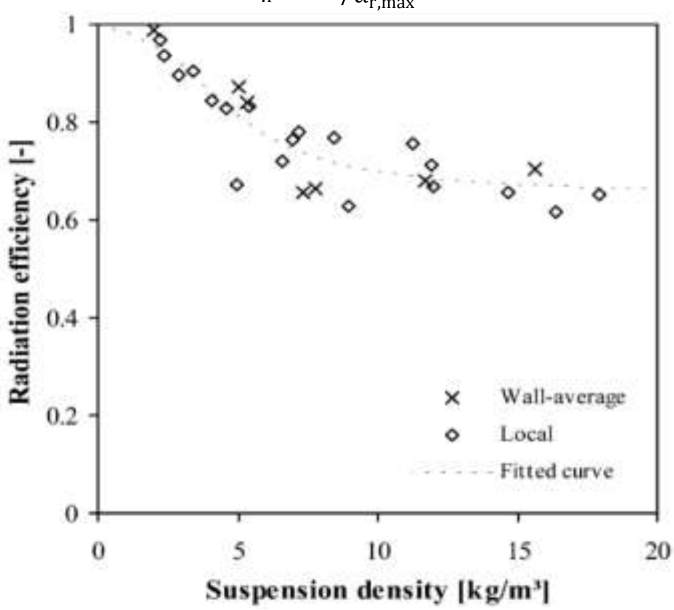

Fig. 3. Radiation efficiency as a function of suspension density

The problems that arise in the steam power plant produce a lack of reliability of the power plant system, and it has an impact on the durability of the leading equipment. Based on the description above, the authors are interested in conducting research "Analysis of Heat Transfer on the Heat Exchanger of Furnace Boiler Circulating Fluidizing Bed in the Power Plant".

II. EXPERIMENTS

II.1 Structure of Fluidized Bed Heat Exchanger (FBHE) and hot circulation loop

Fluidized Bed Heat Exchanger has a structure with a lower fluidization speed than other fluidized bed structures (Fig. 3). Circulating solids enter the heat exchanger through the inlet valve, and then the heat in the particles is transferred to the heat exchanger and exits again at a lower temperature[5].

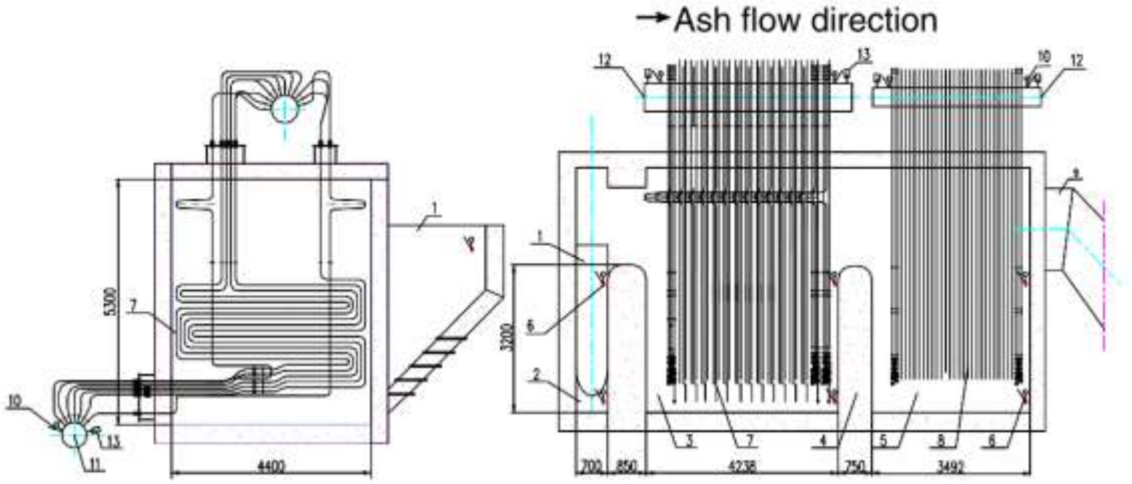

Fig. 4. Fluidized Bed Heat Exchanger Structure

The quantity of coal from the bunker to the combustion chamber is carried out through coal feeders, mill pulverizes, and coal pipes. Arrangement and recording of the amount of coal flow are done with a coal feeder. The lignite was fired in the boiler, and the ultimate analysis is given in Table 1[5].

Table 1: Ultimate analysis of fired coal of boiler

Carbon C_{ar}%	Hydrogen H_{ar}%	Oxygen O_{ar}%	Nitrogen N_{ar}%	Sulfur S_{ar}%	Ash A_{ar}%	Moisture W_{ar}%	Volatile V_{daf}%	Heat Value $Q_{net.}$kJ/kg
36.72	1.87	12.59	1.01	1.66	11.45	34.7	52.7	12,435

II.2 Method and principles of the experiments

A result of the combustion process that occurs in the boiler causes containing heat in the fuel; it moves to water or steam through the Heat Exchanger. The heat absorption of the heat exchanger can be measured by the increase in enthalpy that occurs in the boiler, and the coefficient of heat transfer from each surface in the boiler can be obtained by the Eq (6).

$$K = \frac{Q}{H\,\Delta t}$$

Q is the heat absorbed in the heater, H is the total number of heaters, and Δt is the logarithmic temperature difference, see Eq (7).

$$\Delta t = \frac{(T_a^i - T_s^0) - (T_a^0 - T_s^i)}{\ln\frac{(T_a^i - T_s^0)}{(T_a^0 - T_s^i)}}$$

Where T_a^i and T_a^0 are the solids temperatures at the inlet and outlet of each chamber, T_s^i and T_s^0 are the steam temperatures at the inlet and outlet of each chamber.

In the engineering design, the heat transfer coefficient is calculated by Eq (8), and the denominator includes three parts, bed side thermal resistance $\frac{1}{\alpha_1}$, medium side thermal resistance $\frac{1}{\alpha_2}\beta$ and thermal resistance of heating surface itself $\frac{\delta}{\lambda}$ respectively.

$$K = \frac{1}{\frac{1}{\alpha_1} + \frac{1}{\alpha_2}\beta + \frac{\delta}{\lambda}}$$

Where α1 is nominal heat transfer coefficient from the bed to total heating surface, W/(m2·0C); α2 is the heat transfer coefficient of medium side, W/(m2·0C), and Sieder-Tate equation is adopted for its calculation (see Eq 9) [9]; β is a ratio between the external and internal areas of the heating surface; δ is the thickness of the heating surface tubes, m and λ is the metal thermal conductivity of the heating surface, W/(m2·0C).

$$\alpha_2 = \frac{0.023}{Re^{0.2}} \frac{\omega}{Pr^{0.66}} \left(\frac{\mu}{\mu_w}\right)^{0.14}$$

Where Re is Reynolds number of the medium in the tube, Pr is Prandtl number, ω is the flow velocity, m/s, ρ is the medium density, kg/m3, c is the specific heat of the medium, kJ/(kg·0C), μ is the viscosity with the average temperature of the medium, kg/(m·s), and μω is the viscosity of the medium with metal temperature, kg/(m·s).

The observations were made to collect all data related to the operation of the power plant. Based on calculations of heat transfer, the data occur on the monitor of the controller room. Measuring instruments used in this study were installed in the control room, and they were connected in the field.

III. RESULTS AND DISCUSSION

III.1 Research Results

Data from research results obtained an analysis of displacement calculations in furnace boiler:

Table 4: Log sheet data parameter average value

Load	73.94 MW	**T_{space} HE$_1$**	884.4533 ^{0}C
T_{in} HE$_1$	280.5267 ^{0}C	**T_{space} HE$_1$& HE$_2$**	917.363333 ^{0}C
T_{out} HE$_1$	293.7667 ^{0}C	**$T_{outspace}$**	867.8233 ^{0}C
T_{in} HE$_2$	293.7667 ^{0}C	**P_{space}**	-213.23 Pa
T_{out} HE$_2$	297.0967 ^{0}C	**Q_{water}**	283.4133 ton/day
T_{in} HE$_3$	393.2533 ^{0}C	**Q_{steam}**	273.23 ton/day
T_{out} HE$_3$	452.3167 ^{0}C	**Q_{air}**	297.6033 KNm/day
P HE$_3$	7.34 MPa	**P HE$_1$& HE$_2$**	8.076667 MPa

III.2 The value of heat transfer on the surface at FBHE

Conduction Heat Transfer

Combustion in boiler furnaces occurs through heat transfer by conduction, with the thermal conductivity value of the material at HE1=54 W/m0C, pipe area=1,168.8 m2, temperature difference=13.4 0C (286.5 0K), and boiler height=27.7 m, then obtained qk=-29,973.6 W.

Radiation Heat Transfer

Radiation heat transfer on the heat exchanger is obtained with the value of the Boltzmann constant=5,669.10-8 W/m2.K4, cross-sectional area=1,164.8 m2, and the water temperature at HE=293.7 0C, then obtained qr=491,330 W.

Determine Mean Temperature Difference (LMTD)

Given the value of the inlet temperature HE=280.5 0C, the outlet temperature HE=293.7 0C, the inlet temperature of the combustion chamber=884.4 0C, and the combustion chamber outlet temperature=867.8 0C, with HE flow and combustion chamber in the same direction, then obtained value ΔTm=599.09 0C.

Overall Heat Transfer Coefficient

The internal pipe forced convection value must be determined as well as the outer pipe forced convection. The value of nusselt number=3.6669, thermal conductivity=54 W/m 0C and inner diameter=0.054 m, the overall heat transfer coefficient (U0) value is 0.598 W/m0C.

Amount of Heat Absorbed

After knowing the overall heat transfer coefficient value, the amount of heat was absorbed by the fluid in HE is 88.515 kJ/kg.

Table 5: Comparison between actual data and commissioning

specified parameters	HE_1 (wall tube)		HE_2 (evaporator)		HE_3 (platen superheater)	
	actual	Commissioning	actual	Commissioning	actual	Commissioning
conduction flow rate	-29,973 W	-10,672.3 W	-1,924.56 W	-1,749.71 W	-27,426.47 W	-13,931.49 W
radiation flow rate	491,330 W	555,846.57 W	51,939.041 W	122,124.23 W	262,117.77 W	256,826.7 W
different average temperatures	599.09 ^{0}C	235.83 ^{0}C	599.92 ^{0}C	235.83 ^{0}C	468.2 ^{0}C	446.2 ^{0}C
overall heat coefficient	0.598 W/m^2 ^{0}C	0.598 W/m^2 ^{0}C	0.829 W/m^2 ^{0}C	0.829 W/m^2 ^{0}C	0.799 W/m^2 ^{0}C	0.8000 W/m^2 ^{0}C
heat absorbed	88.515 kJ/kg	11.99 kJ/kg	1.73 kJ/kg	1.44 kJ/kg	271.06 kJ/kg	72.82 kJ/kg

III.2 Discussion

Based on observations and data collections, the data is known that the Heat Exchanger material used in Wall tube and Evaporator is carbon steel SA 210 A with a carbon percentage of 0.27%, a thermal conductivity value of 54 W/m 0C. Superheater platen uses carbon low alloy steel material with a carbon presentation of 1% and a thermal conductivity value of 43 W/m0C.

The conduction flow rate at HE1=-29,973.6 W, HE2=-1,925.56 W, and HE3=-27,426.47 W, the minus sign (-) in the calculation results shows that heat moves under high temperature (combustion chamber) leading to low temperature (working fluid). The high conduction flow rate in HE1 is due to the wide cross-section in HE1 that surrounds the boiler furnace while for HE 2 and 3 which have be a vast difference between the two is due to the higher number of pipes in HE 3 and the different material used.

The radiation rate that occurs at HE1=41,330 W, HE2=51,939 W, and HE3=262.117 W shows that the high radiation emission at HE3 is influenced by the temperature of the working fluid and it was produced and also was caused by the working fluid at HE3 which has turned into dry steam.

The difference in average temperature which was measured by the LMTD method obtained data at HE1=599.09 0C, HE2=599.92 0C, and HE3=468.2 0C. This data shows the value of the heat transfer in the flow system, especially on heat exchangers.

The overall heat transfer coefficient at each HE has been the same value, namely HE1=0.598 W/m2 0C, HE2=0.829 W/m2 0C, and HE3=0.799 W/m2 0C. The overall coefficient of heat transfer at HE3 is greater than HE 1 and 2, and due to the material which was used is different. The amount of the heat absorbed for each Heat Exchanger is HE1=88,515 KJ/Kg, HE2=1.73 KJ/Kg, and HE3=271.06 KJ/Kg.

From the results of the comparison actual data and commissioning, the data is shown that the value for each commissioning is getting smaller and it was excepted in the overall heat coefficient. From the calculation data, there is also no visible movement or slaking of the heat exchanger in the Furnace Boiler because the fluidizing air which contained in the furnace is sprayed in the direction of the combustion process.

IV. CONCLUSIONS

Some things can be concluded from the results of the calculation analysis, as follows:

1. The heat transfer coefficient for each heat exchanger in the actual state includes HE1=0.598 W/m2 0C, HE2=0.829 W/m2 0C, and HE3=0.799 W/m2 0C, then at the commissioning state of 0.8 W/m2 0C.
2. The amount of heat absorbed for each heat exchanger in the actual and commissioning state is HE1=88,515 KJ/Kg for the actual measurement and 11.99 KJ/Kg for the commissioning, HE2=1.73 KJ/Kg for actual measurements and 1.44 KJ/Kg for the commissioning, and HE3=271.06 for actual measurements and 72.82 KJ/Kg for commissioning.
3. The difference in the amount of heat absorbed during the commissioning and actual process is due to the reducing heat that can be absorbed during the preheater and it causes an increase in heat absorption for each heat exchanger in the Boiler Furnace.

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