MODELING AND SIMULATION OF THE BOILERS AT AL-MUSSAIB THERMAL STATION

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ABSTRACT

A mathematical model is developed for simulating the steady state performance of a 320 MW boiler at Al-Mussaib Thermal Station. The boiler referred to is a drum type natural circulation unit, its continuous operation rate for steam is 980 ton/h at a temperature and pressure of 540 oC and 210 bar at full load respectively.

The boiler system is divided – for the convenience of analysis- into twelve interactive zones according to its physical construction, and the energy conservation principle is then applied to each zone to form the sub-system models; finally all the sub-system models are coupled together to form a complete system model for the steady state performance for the boiler unit.

A set of empirical correlations has been employed for the evaluation of heat transfer and physical properties to determine the system parameters. The validity of the model and the assumptions used in modeling have been tested by running the program using the design input variables taken from the manufacturer manuals, and the simulated results have been compared with that of design data. Also the simulated results have been checked with some actual operation data taken from the data sheets of the boiler operation.

INTRODUCTION

A boiler is a device used for generating steam, which can be used for the production of power or for the heating purposes. The thermal power station boiler usually consists of different equipments working together with the aim of converting chemical energy of fuel into heat energy in the steam which is generated at a certain pressure and temperature. The energy stored in the steam is converted into kinetic energy in the turbine then into electrical energy in the power generator. The steam from the turbine is condensed in the condenser and recirculated to the boiler[1].

For these reasons, the thermal power station plays a very important role in an electric power system, it is obvious that the performance of the boiler may directly affect the whole power system. Therefore, it is logical to seek better conditions for improving the performance of the power plant station[1,2].

Mathematical modeling of the boiler system and its simulation gives a better understanding of the fundamental characteristics and is mainly used to represent the boiler parts by sub models to describe the boiler operation as accurately as possible. The simulation model should take into consideration all processes occurring in the boiler. The purpose of simulation model is to predict the correct trends of boiler behavior for any expected change taking place in the input variables[3, 4]. Hence, a mathematical model, which approximates a boiler to the point that it predicts these trends with reasonable accuracy, is adequate for our purpose.

The problem of performance of a thermal power plant boiler of specified shape and size, may be said to be solved when the temperature pattern in the gas side and steam side along the unit can be predicted. The problem can be solved if sufficient knowledge exists concerning the factors which affect the combustion, the flow of gases and steam, and the transfer of heat by radiation and convection at every point in the

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system. Hence, an aim of the present study is to determine the important parameters affecting the performance of the boiler system existing at Al-Mussaib Thermal Power Station to enable the operators to appreciate the corrective actions necessary to maintain satisfactory operation. The of the boiler under consideration is shown in Fig.(1)[5,6].

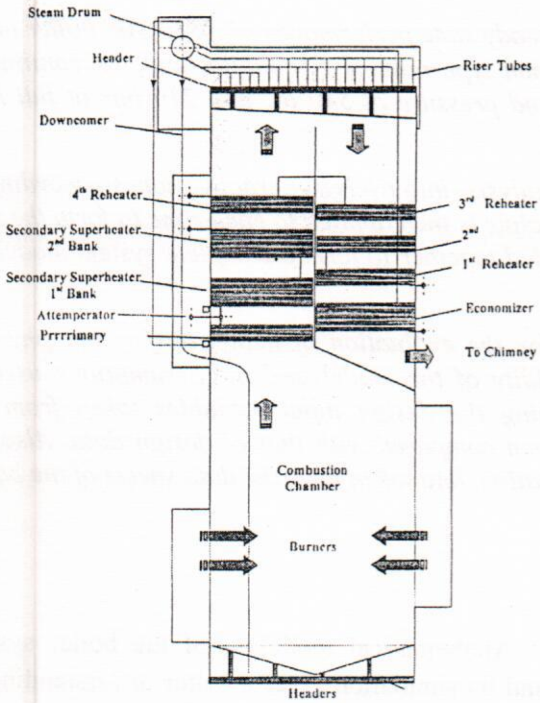

Fig. (1) Babcock and Wilcox boiler system

Mathematical Model

A mathematical model, established by analytical approach, for the steady state operation of the Babcock & Wilcox boilers at Al-Mussaib Power Station is presented in this work. The boiler system was divided into twelve interactive zones, namely; 1. Radiation zone 2. Primary superheater zone (1st bank) 3. Primary superheater zone (2nd bank) 4. Attemperation zone 5. Secondary superheater zone (1st bank) 6. Secondary superheater zone (2nd bank) 7. Reheater zone (4th bank) 8. Reheater zone (3rd bank) 9. Reheater zone (2nd bank) 10. Reheater zone (1st bank) 11. Eocnomizer zone and 12. Steam drum zone. The zones was selected according to their physical construction and the energy balance is applied to each zone to form the subsystem models; finally, all these subsystem models are coupled together to form a complete boiler system model. Calculations were made using a set of suitable empirical correlations to determine the system parameters. The model and some necessary assumptions have been tested by running the computer program which simulates the behavior of the boiler under consideration under several loading conditions and comparing the results obtained with the operation data given in the manuals of manufacturer as well as with the data normally available in the operating plant. The model allows an educational analysis of factors influencing the heat transfer processes.

Boiler configuration

The boiler under consideration is shown in Figure (1) and the schematic construction diagram is shown in Fig. (2). It is a Babcock & Wilcox boiler with a Maximum Continuous Rating (MCR) of 980 ton steam (203 bar) per hour, presently in operation at Al-Mussaib Thermal Power Plant Station with about 70% load[6].

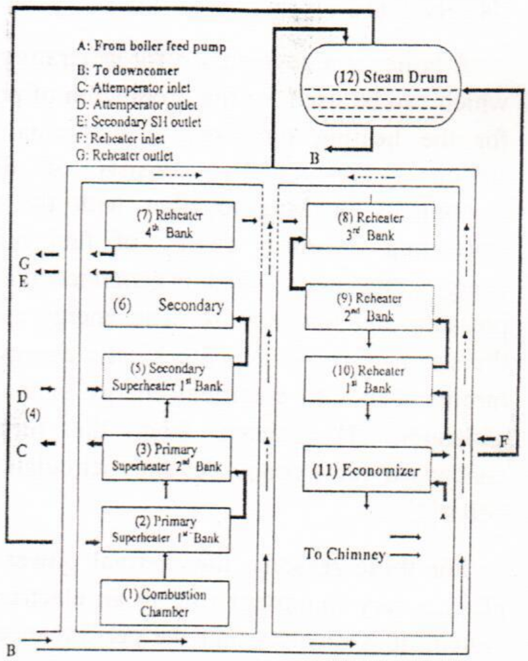

Fig. (2) Schematic construction diagram for the Babcock and Wilson boiler under study

System description

The combustion chamber is 24.4 m in height, 10.97 m in width and 13.72 m in length. The walls of enclosure are covered by tube sheets made of stainless steel tubes connected by sheet plates. The furnace is fired with a fuel oil through burners in two rows of 8 burners in each row located in the lower part of the chamber below the combustion gas exit to the convection section. Table (3.1) shows the essential information about the boiler configuration.

The Process. In the combustion chamber the process of burning the fuel is carried out and the heat transfers by radiation and convection modes. According to Stefan-Boltzman Law, the rate of heat transfer in the radiative mode at a constant emissivity varies approximately with the fourth power of the absolute temperature[7], and from the fact that the rate of heat transfer by convection varies directly with the temperature difference, it is reasonable to assume that the heat transfer in the combustion chamber is dominated by radiation since the flame temperature is much higher than that of the hot gases.

Water is fed into the boiler by the feed water pumps. In the economizer, water absorbs heat from the flue gases leaving the boiler and its temperature increases to a certain value which is usually below the saturation temperature, corresponding to the drum pressure. From the economizer, water flows into the drum from which the water flows to the water walls through the downcomer in a natural circulation mode. In this circulation, a great amount of heat will transfer to the water so that boiling takes place, and the motion of fluid is setting up by buoyancy effects resulting from the density difference caused by the temperature difference in the fluid. As the water from the bottom of the water walls flows upward, the process of heat transfer takes place, and at the top of the water walls a certain percentage of the water may be vaporized. When the water-steam mixture flows back into the drum, condensation and vaporization take place simultaneously. The water which separates from the water-steam mixture will mix with the water at the bottom of the drum. This water has a temperature slightly below the saturation temperature and will flow into the downcomer with water from the economizer for the next circulation. The separated steam leaves the drum and enters the superheater section.

In the superheater section, the steam passes through various tube banks, some are mounted in the horizontal position and some are vertical. This superheater section is divided into primary superheater and secondary superheater each consisting of two banks of tubes. There is a spray attemperator between the outlet of the second bank of the primary superheater and the inlet of the first bank of the secondary superheater. The attemperator is used only for controlling the temperature of the steam flowing to the high pressure turbines.

The exhausted steam from the high pressure turbine is reheated in four reheaters mounted in the convection section in order to raise its temperature to be used in the driving of the intermediate pressure turbine.

General Assumptions. The following general assumptions are used in order to facilitate the mathematical formulation of the system:

1. Each zone is treated as a lumped-system.
2. The mass flow rates of both the water and steam in each zone are constants.
3. The continuity of the mass flow rate and temperature is considered as the boundary condition for fluid flow and heat transfer between two adjacent zones.
4. The loss in heat energy is occurred only in the radiation zone.
5. The potential and kinetic energies are negligible.
6. Enthalpy is a function of temperature at a certain pressure and it is correlated using the steam table data.
7. The combustion of fuel oil is complete.

The mathematical model of the boiler system should be sufficiently accurate to represent the behavior of the boiler and also sufficiently simple for easiness of application to simulate the real operation of the system.

Radiation Zone. Heat transfer in this zone of the boiler occurs largely by radiation from the flue gases but also significantly by convection. The combined effect is represented by[4]:

$$\frac{Q_R}{A_R} = \alpha F \sigma \left(T_g^4 - T_t^4 \right) + h_{Rc} \left(T_g - T_t \right) \qquad (1)$$

The radiative properties of a gas depend on its chemical nature, its concentration, and temperature. In the thermal range, radiation of flue gas is significant only from the triatomic molecules H_2O, CO_2 and SO_2. The emissivity of such a gas is represented as a function of temperature and the product (PL) of the partial pressures (P) of water vapor and carbon dioxide (SO_2 composition is small and usually neglected) and the path of travel defined by the mean beam length (L). The convective heat transfer coefficient (h_{Rc}) can be calculated using Dittus and Boettler relation[7, 8]

$$Nu_d = \frac{h_i d_i}{k} = 0.023 Re_d^{0.8} Pr^{0.4} \qquad (2)$$

The combustion chamber in the present analysis was considered as two parts, the water wall tubes and the shield tubes which is taken as the first row of the first bank of the primary superheater. In each part the contribution of both radiation and convection was calculated.

The heat balance equation in the combustion chamber is[4]:

$$\frac{Q_R}{\alpha A_R F} = \frac{Q_n}{\alpha A_R F} \left(1 + \frac{Q_a}{Q_n} + \frac{Q_f}{Q_n} - \frac{Q_\ell}{Q_n} - \frac{Q_g}{Q_n} \right) \qquad (3)$$

The total enthalpy released in the furnace is calculated as:

$$Q_n = \dot{m}_f H_{CV} \qquad (4)$$

The enthalpy of entering air is calculated as:

$$Q_a = \dot{m}_a Cp_a \left(T_a - T_{ref} \right) \qquad (5)$$

The enthalpy of entering fuel is calculated using the equation:

$$Q_f = \dot{m}_f Cp_f \left(T_f - T_{ref} \right) \qquad (6)$$

The enthalpy of gas leaving the radiant zone is calculated as:

$$Q_g = \dot{m}_g Cp_g \left(T_g - T_{ref} \right) \qquad (7)$$

The mass flow rate of combustion gases leaving the radiant zone is calculated as:

$$\dot{m}_g = \dot{m}_a + \dot{m}_f + \dot{m}_{gcir} \qquad (8)$$

Emissivity and Exchange Factor

The emissivity of gases in the combustion chamber is calculated by the equation[4, 9, 10]:

$$\varepsilon = a_1 + b_1 (PL) + c_1 (PL)^2 \qquad (9)$$

$$L = 3.6 \frac{V}{A} \qquad (10)$$

The constants are calculated using the following empirical equations[4]:

$$Z_1 = T_g / 1000 \quad \text{(Tg in Rankine)} \qquad (11)$$

$$a_1 = 0.47916 - 0.19847 Z_1 + 0.022569 Z_1^2 \qquad (12)$$

$$b_1 = 0.04729 - 0.0699 Z_1 - 0.01528 Z_1^2 \qquad (13)$$

$$c_1 = -0.000803 - 0.00726 Z_1 + 0.001587 Z_1^2 \qquad (14)$$

$$P = 0.288 - 0.229 X_a + 0.09 X_a^2 \qquad (15)$$

The exchange factor is calculated using the following equation

$$F = a_2 + b_2 \varepsilon + c_2 \varepsilon^2 \qquad (16)$$

The constants are calculated using the following empirical equations:

$$Z_2 = A_w / \alpha A_{Cp} \qquad (17)$$

$$a_2 = 0.00064 + 0.591 Z_2 + 0.00101 Z_2^2 \qquad (18)$$

$$b_2 = 1.0256 + 0.4908 Z_2 - 0.058 Z_2^2 \qquad (19)$$

$$c_2 = -0.144 - 0.552 Z_2 + 0.040 Z_2^2 \qquad (20)$$

Tube Wall Temperature

In order to evaluate the tube wall temperature (Tt), the heat transfer rate from the outside surface of the water wall tubes (at a temperature Tt) to the inside of the tubes (at a saturation temperature Tws) can be expressed as[7]:

$$Q_R = \frac{T_t - T_{ws}}{\frac{1}{h_{wi}A_i} + \frac{d_i \ln(d_o/d_i)}{2\pi k}} \quad (21)$$

The heat transfer coefficient (hwi) inside the water wall tube is calculated using the following procedure suggested by Chen et al.[11]

He proposed that the heat transfer coefficient to saturated liquids in convective flow is the sum of microconvective and macroconvective heat transfer coefficients. The latter, hmac, is related to the Dittus Boelter equation[7]:

$$\frac{h_L d_i}{k_L} = 0.023 Re_d^{0.8} Pr^{0.4} \quad (22)$$

for hL by a factor f which is correlated by the reciprocal of the Martinelli parameter, Xtt. The coefficient hL is for the liquid fraction of the flow; thus:

$$\frac{h_L d_i}{k} = 0.023 \left[\frac{d_i G(1-x)}{\mu_L}\right]^{0.8} Pr^{0.4} \quad (23)$$

and: $h_{mac} = f h_L$ (24)

with:

$$X_{tt} = \left(\frac{1-x}{x}\right)^{0.9} \left(\frac{\rho_g}{\rho_L}\right)^{0.5} \left(\frac{\mu_L}{\mu_g}\right)^{0.1} \quad (25)$$

The microconvective coefficient, hmic, can be correlated from the Forster and Zuber(29) relationship for pool boiling by allowing for the suppression of boiling due to pressure drop caused by the flow. Thus, Chen(11) correlates a suppression factor, S, in terms of the effective Reynolds number (Ree) expressed as $dG(1-x)f^{1.25}/\mu_L$ which can be used in the following equation:

$$\frac{h_{mic} r_b}{S k_L} = 0.0015 Re_b^{0.62} Pr_L^{0.33} \quad (26)$$

where:

$$r_b = \frac{\Delta T}{\lambda \rho_g} \left(\frac{2\pi k_L \rho_L Cp_L \sigma_{ST}}{\Delta P}\right)^{0.5} \left(\frac{\rho_L}{\Delta P}\right)^{0.25} \quad (27)$$

and:

$$Re_b = \frac{\pi k_L Cp_L}{\mu_L} \left(\frac{\rho_L \Delta T}{\rho_g \lambda}\right)^2 \quad (28)$$

The convective coefficient of the two phase is:

$$h_{TP} = h_{mac} + h_{mic} \quad (29)$$

Primary Superheater. The primary superheater is a section mounted at the exit of flue gases from the combustion chamber, it consists of two banks of tubes bounded together by a set of metal plates. The plates are welded to the outside of the tubes to improve the heat transfer.

The gases enter the primary superheater are that coming from the combustion chamber at Tg. The primary superheater is divided into two interactive zone, namely; the first bank and the second bank. The heat transfer rate in these banks can be expressed by the following equation:

$$Q_C = \dot{m}_g \overline{C}p_g (T_{gin} - T_{gout}) = \dot{m}_s \overline{C}p_s (T_{sout} - T_{sin}) = UA(\overline{T}_g - \overline{T}_s) \quad (30)$$

The heat transfer coefficients are then calculated using the average temperature $\overline{T}$

$$\overline{T}_j = \frac{T_{j1} + T_{j2}}{2} \quad (31)$$

Where j refers to gas or steam and 1 and 2 refer to inlet and outlet conditions.

The heat transfer coefficient inside the water wall tubes at the primary superheater level (hwi) is calculated using the same equations used in the radiation zone (Eq. 22-29) and that inside the PSH tube bank by using Eq. 2. The outside heat transfer coefficient is calculated using the following equation for flow across a tube bank:

$$Nu_d = \frac{h_o d_o}{k} = 0.36 \left(\frac{Cp\mu}{k}\right)^{1/3} \left(\frac{d_o G_{max}}{\mu}\right)^{0.8} \quad (32)$$

For the vertical section of the tube bank, at which gases flow in the direction of tubes, the equation of Nusselt[7] can be used to calculate the heat transfer coefficient.

$$Nu_L = \frac{h_o L}{k} = 0.037 Re^{0.8} Pr^{0.33} \quad (33)$$

The overall heat transfer coefficient in the tube banks of the convection section is:

$$U_o = \frac{1}{R_o + R_i + R_t + R_{fo}} \quad (34)$$

Ro = Outside tube resistance $= \frac{1}{h_o}$ (35)

Ri = Inside tube resistance $= \frac{A_o}{h_i A_i}$ (36)

Rt = Tube metal resistance $= \frac{d_o}{2\pi k} \ln \frac{d_o}{d_i}$ (37)

Rfo = Fouling resistance, taken as 0.0001 m2 K/W

Spray Attemperator. The steam from the second bank of the primary superheater is passed through the superheater spray attemperator in which feed water from the boiler feed pump is sprayed into the steam in order to control its temperature. Under normal operating conditions, it is required that the temperature of the superheated steam be kept within specified range around its rated value (about 540oC). This regulation of temperature is quite important because it contributes to the fatigue of metallic parts and it is limited by turbine design constraints.

An energy balance is made to calculate the temperature of the steam at the inlet of the 1st bank of the secondary superheater.

Since the flow rate of steam after attemperation is the sum of the steam flow rate from the primary superheater and that of attemperation, i.e.,

$$\dot{m}_{SSH} = \dot{m}_{att} + \dot{m}_{PSH} \quad (38)$$

and

$$T_{att} = \frac{\dot{m}_{PSH}\overline{C}p_s T_{PSH} + \dot{m}_{att}\left(\overline{C}_{PL} T_{bfw} - \lambda\right)}{\dot{m}_{SSH}\overline{C}p_s} \quad (39)$$

Secondary Superheater. The heat transfer treatment of the above tube banks (1st and 2nd banks) is similar to that for the primary superheater.

Reheater Section. The first part of this section (reheaters 1, 2, 3) is mounted above the economizer (low temperature section) at which the superheated steam (pressure 48 bar and temperature 350 oC) which is coming from the exit of high pressure turbine (HPT) enters to the first reheater. The second part (reheater 4) is mounted above the secondary superheater (high temperature section) from which the superheated steam is sent to the intermediate pressure turbine (IPT). Each bank of the reheater was treated as a lumped parameter system with average wall and gas temperatures. Similar calculations to that of previous sections were done in this section to find the gas and steam outlet temperatures in each bank.

Economizer. The economizer consists, as the other banks, of a number of metal tubes bound together by metal plates. The heat absorbed by the water in the economizer is the difference in energy at the inlet and outlet of the tubes.

Steam Drum. Water from the economizer enters into the drum via holes at the top of the header and mixes with the drum water, it is assumed that total mixing takes place in the drum is:

$$\begin{Bmatrix}\text{Mass flow rate}\\ \text{from economizer}\end{Bmatrix} + \begin{Bmatrix}\text{Liquid mass flow}\\ \text{rate from risers}\end{Bmatrix} = \begin{Bmatrix}\text{Downcomer mass}\\ \text{flow rate}\end{Bmatrix}$$

$$\dot{m}_e + (1-x)\dot{m}_{ri} = \dot{m}_{dc} \quad (40)$$

The liquid heat balance yields:

$$\begin{Bmatrix}\text{Energy in water}\\ \text{from economizer}\end{Bmatrix} + \begin{Bmatrix}\text{Energy in water}\\ \text{from risers}\end{Bmatrix} = \begin{Bmatrix}\text{Energy in water}\\ \text{leaving to downcomer}\end{Bmatrix}$$

$$\dot{m}_e H_{Le} + (1-x)\dot{m}_{ri} H_{Lri} = \dot{m}_{dc} H_{Ldc} \quad (41)$$

The steam mass balance is:

$$x\dot{m}_{ri} = \dot{m}_{PSH} \quad (42)$$

Physical Properties. In order to complete the mathematical model of the boiler system, the prediction of the physical properties of water, steam, air, combustion gases...etc. is required at different conditions. The physical properties such as density, viscosity, heat capacity, thermal conductivity...etc. are taken from tables and graphs[7, 12, 13, 14] as functions of temperature and pressure and correlated in polynomial expressions by curve fitting methods.

Computer Program. The calculation procedures were carried out with practically no restriction on difficulty and with the main objective of accuracy. A computer program is developed to calculate the temperature distribution and heat transfer in each part of the boiler in order to find the effects of various input parameters on the normal operation of the boiler.

The computer program, written in Quick Basic Language consists of a main program and many subroutines and functions. The main part and its subroutines and functions are described in the following subsections.

The main program controls the reading of the input data, calls different subroutines to perform the calculations and print the output of the program. The computational procedure is as follows:

1. The program read various input data such as physical properties, dimensions, known temperatures, flow rates, operating pressure.
2. It calculates the necessary quantities such as areas of different zones, heat released in the combustion chamber and heat transfer in each zone.
3. It calls the different subroutines and functions to perform the specific calculations for different parts of the boiler system.
4. It calculates the temperature distribution in the different zones of the boiler.
5. It opens a data file to save the program results in each step of program calculations.
6. It prints and plots the results for each step of calculations.

RESULTS AND DISCUSSION

The output results were represented as temperature profiles for both flue gases side and steam side through boiler zones which are indicated as numbers in the figures showing these profiles. Fig.1 shows typical temperature profiles in the boiler for both flue gases and steam sides at certain operating conditions. The temperatures always refer to outlet stream temperature of each zone. In the gas side, the curve is continuous along the whole zones of the boiler, whereas in the steam side, the curve consists of two discrete parts. The first part belongs to the steam flowing from the steam drum through the primary and secondary superheaters to the high pressure turbine (HPT). The second part of the curve represents the temperatures of the steam leaving the high pressure turbine entering the reheaters section. It enters the first reheater bank passing through the second, third bank (the low temperature region) then to the fourth reheater bank (high temperature region) and then finally to intermediate pressure turbine (IPT).

The temperature of the subcooled water exiting from the economizer is indicated by a circle on the y-axis at zone no. 11 as shown in Fig.1. Examining Fig.1, it is clear that the temperature drop of flue gases is large comparing to the rise in the steam temperature, this is due to the large temperature difference (driving force) in the first bank of the primary superheater (1-2 in the gas temperature profile curve), then the drop becomes less in the second bank of the primary superheater (2-3 in the same profile) because the rate of heat transfer in this zone is less due to the smaller difference between the flue gases and steam.

Table (1) The end design and simulated parameters of the boiler

1. Flow Quantities (kg/sec)	70% Load	100% Load	MCR	Simulation for 70% Load
Steam at SH outlet	167.97	250.75	272.22	167.97
Steam to RH	150.20	221.53	239.65	150.20
Fuel burned	12.05	16.98	18.20	12.05
Air at F.D.F outlet	215.17	27.5	293.50	215.17
Recirculation gas to furnace	80.72	57.14	45.88	80.72
Spray attemperation	10.83	6.14	2.80	10.83
2. Excess Air, %				
Furnace	15	5	5	15
Leaving economizer	16	6	6	16
3. CO_2 by Dry Vol., %				
Furnace	13.3	14.7	14.7	13.3
Leaving economizer	13.2	14.6	14.6	13.2
4. O_2 by Dry Vol., %				
Furnace	2.9	1.1	1.1	2.9
Leaving economizer	3.1	1.3	1.3	3.1
5. Steam and Water Pressure (bar. g)				
Sec. S.H outlet	168	170.7	171.6	170
Sec S.H. inlet	169.9	175.0	176.5	170
Drum	171.6	179.3	181.7	170
R.H outlet	25.5	38	41.1	46
R.H inlet	26.9	39.9	43.2	46
Economizer inlet	173.6	182.1	185.8	170
6. Temperature, (°C) of Steam and Water				
SSH outlet	541	541	541	540
SSH inlet	382	387	389	380
PSH inlet	353	357	358	358
PSH outlet	410	397	395	438
RH outlet	541	541	541	533
RH inlet	309.9	338	345.3	305
Economizer outlet	280	287	289	280
Economizer inlet	230.8	215.8	256.4	250
7. Gas				
Leaving furnace	1090	1250	1290	1115
8. Air				
Ambient air	23	23	23	25

In the attemperation zone which represents a mixing point rather than a zone, the effect appears as a straight line in the flue gases temperature profile (3–4). In the first bank of the secondary suerheater, the rate of heat transfer becomes large again due to the increase in the temperature difference between the gas and the steam. The same mechanism of heat transfer are always true for the other zones. It is shown that the temperature drop in the reheater section is also high due to the large surface area of the reheater banks (about four times of the PSH area) which compensates the decrease in the heat content of the flue gases. In the steam side, the increase in temperature profile corresponds to the decrease in temperature profile of flue gases in each zone.

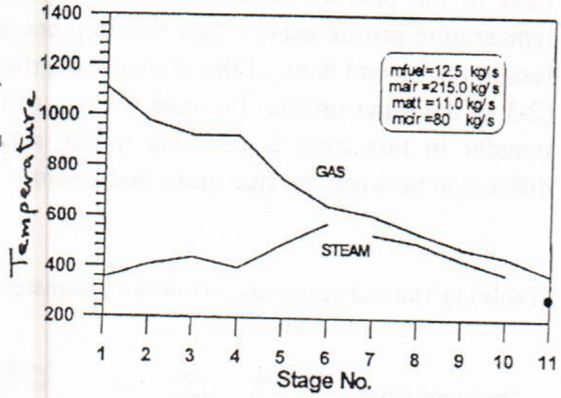

Fig. (1) Temperature profile for gas and steam streams

Effect of Fuel Flow Rate. The general effect of fuel flow rate on the boiler operation is to increase all the temperatures in the boiler, but it mostly affects the temperature of the radiation zone due to the formation of soot which increases the luminosity of the flame. The effect of variation of fuel oil flow rate on the temperature profiles of flue gases is shown in Fig..2 for certain values of air flow rate (215 kg/s), gas recirculation rate (80 kg/s), and attemperation rate (11 kg/s). In this figure, it is shown that the increase in fuel flow rate leads to an increase in the temperature of the flue gases for the whole boiler zones in the range of fuel oil flow rate studied in this work. Also the rate of heat transfer in all zones becomes higher with larger fuel oil flow rates.

Figure 3 shows the effect of increase in fuel flow rate on the steam temperature profile in the various zones of the boiler. Following the temperature profile of the steam, the most important point concluded is that the difference between steam temperature exits from the secondary superheater (going to HPT) and the steam temperature exits from the fourth reheater (going to IPT) becomes larger with the increase in fuel oil flow rate. This represents an undesirable conditions for the normal operation of the turbines and must be avoided.

Effect of Air Flow Rate. The effect of air flow rate on gas temperature profile is shown in Fig.4 for a certain values of other variables. It is clear that the increase in air flow rate will decrease the radiation zone temperature due to the dilution of the gases in the zone, which leads to decrease the temperature and luminosity of the flame, therefore the heat absorption by the water wall tubes in this zone will decrease. At the same time, it is shown that the temperature of the flue gases at the exit of the boiler increases when the air flow rate is increasing. Although the heat content of the gases leaving the radiation zone is high, a considerable amount of heat leaving with the gases at relatively high temperature out of the boiler can not be avoided due to the limiting conditions of the heat transfer in the convection zone.

For the steam temperature profile it is shown from Fig.5 that the increase in air flow rate will cause an increase in the steam temperature at the region beyond the attemperation zone.

Effect of Attemperation. The effect of attemperation flow rate on the gas and steam profile was studied. Figure 6 shows the effect of increasing the attemperation rate on the flue gases temperature profile. It is shown that the attemperation affects slightly the temperature of the gas while the steam temperature at the exit of the secondary superheater varies largely with attemperation rate. This is due to that the heat given up by the steam during the process of attemperation is taken by the attemperation water in three steps. First, its temperature is raised to that of saturated water; then the water is evaporated (absorbs large quantity of heat); and finally the steam generated is raised to the final condition of temperature outlet. This explains the use of attemperation for controlling the steam temperature as shown in Fig.7.

Effect of Gas Recirculation. The effect of gas recirculation at certain values of fuel flow rate, air flow rate and attemperation rate was studied. Figure 8 represents the change of the gas temperature with gas recirculation rate for the whole zones. The general effect of the gas recirculation is to decrease the radiation section temperature, and increase the convection section temperature. In the radaition zone, the temperature decreases because of the dilution of the gases in the zone, which decreases the heat absorbed by the waterwall tubes. On the other hand, a large volume of gases leaves the radiation zone with large heat content will increase the heat transfer rate in the convection section resulting in an increase of steam temperature in this section. This effect is more obvious in the reheater zone due the large heat transfer area in this zone and the large temperature difference. On the steam side, the effect of gas recirculation is very clear in the reheaters section while the superheater temperature increase only slightly by the increase of gas recirculation rate as shown in Fig.9.

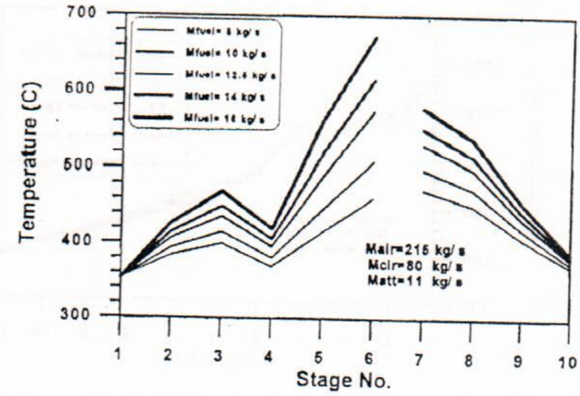

Fig. (3) Effect of fuel flow rate on stream profile

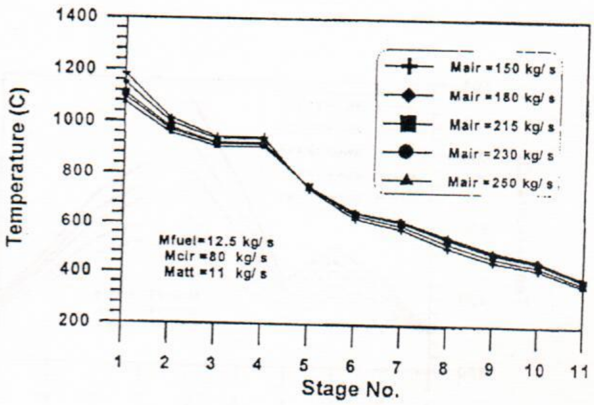

Fig. (4) Effect of air flow rate on gas rofile

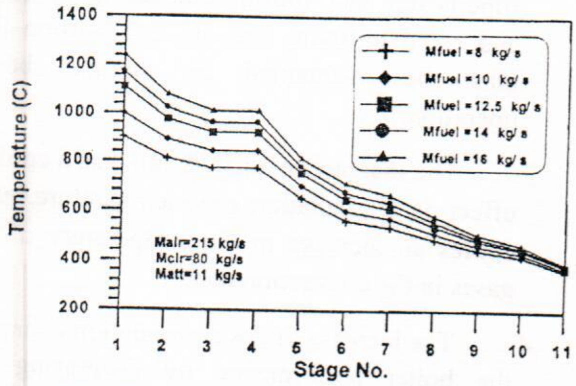

Fig. (2) Effect of fuel flow rate on gas profile

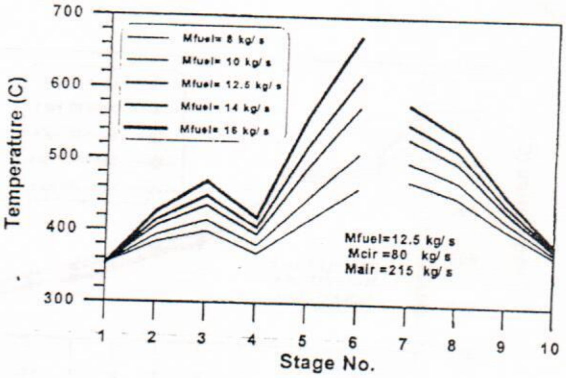

Fig. (5) Effect of air flow rate on stream profile

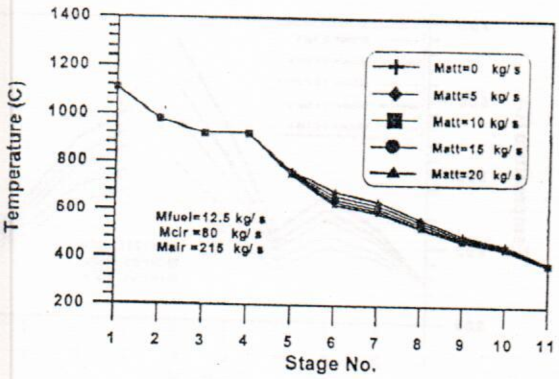

Fig. (6) Effect of attemperation on gas profile

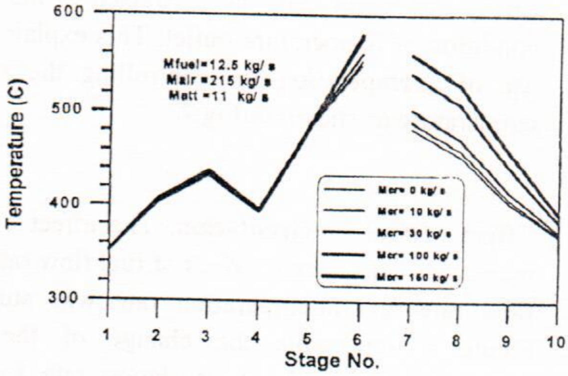

Fig. (9) Effect of gas circulation on steam profile

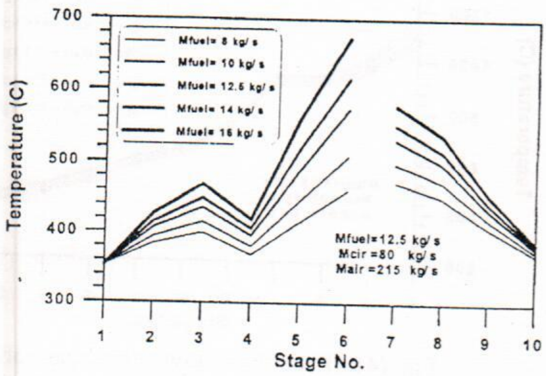

Fig. (7) Effect of fuel flow rate on stream profile

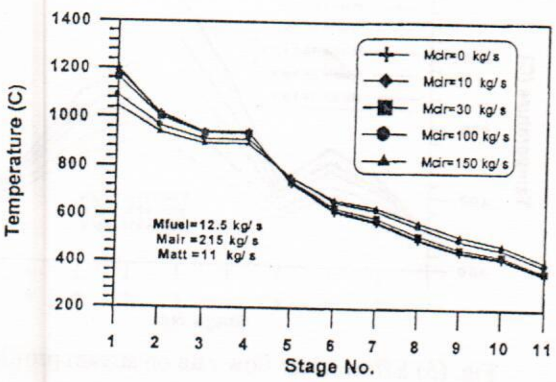

Fig. (8) Effect of gas circulation on gas profile

CONCLUSIONS

The following conclusions can be drawn from the present work:

1. In order to ensure stable operation of a boiler it is basically required to remove actively and correctly, the heat released in the furnace by the motion of working fluid at suitable flow rate.

2. The difference between the exit temperatures of the secondary superheater and the fourth reheater becomes larger with the increase in fuel flow rate, which represent an undesirable operation of the boiler. There is always a certain value of fuel flow rate at which the exit temperatures of secondary superheater and fourth reheater is identical, and equal to about 540 oC, a condition that must be maintained for normal boiler operation.

3. The increase in air flow rate has a cooling effect on the radiation zone temperature but it causes an increase in the temperature of the gases in the convection zone.

4. The increase of gas recirculation enhances the boiler performance by decreasing the radiation zone temperature with only slight increase in temperature of the flue gases leaving the boiler.

5. The major effect of the attemperation is to change the temperature of the steam side without changing the temperature of the gas side in order to control the degree of superheat.

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