# Influence of Feed Water Heaters on the Performance of Coal Fired Power Plants

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***Abstract:*** **This paper shows the effects of the feed water heaters on the performance of coal fired power plants. By adding the feed water heaters in power plant cycle, the overall efficiency of the power plant is increased by 2.4 %. Improving the power plant efficiency could alleviate the negative effect of coal consumption on $CO_2$ emission. By means of thermodynamic optimization it is propose to include the feed water heaters in power plant cycle, achieving optimum power plant efficiency. Simulations have been carried out using HMBD software. Results show a feasible improvement of the overall power plant efficiency. This implies a direct reduction of $CO_2$ emission of about 1.3 %. Moreover, the financial analysis confirms the feasibility of proposal analyzed and shows the additional yearly incomes.**

***Keywords*: Power plant; Feed water heaters; Plant efficiency.**

**Nomenclature**

| | | |
|---|---|---|
| HMBD | - | Heat and Mass Balance Diagram. |
| m | - | Mass flow rate (kg/s) |
| Q | - | Energy (J/s) |
| h | - | Enthalpy (kcal/kg) |
| H | - | Internal energy (Kcal) |
| P | - | Pressure (bar) |
| ρ | - | Density (kg/m$^3$) |
| T | - | Temperature (Deg C) |
| V | - | Volume (m$^3$) |
| BIS | - | Bureau of Indian Standard. |
| H.E.I | - | Heat Exchanger Institute |
| TEMA | - | Tubular Exchanger Manufacturer Association |
| ASME | - | American Society of Mechanical Engineers |
| GTTD | - | Greater terminal temperature difference, ($^0$C) |
| LTTD | - | Lesser terminal temperature difference, ($^0$C) |
| U | - | Overall heat transfer coefficient, W/m$^2$ $^0$C |
| A | - | Heat transfer surface area, m$^2$ |
| F | - | Correction factor for the log mean temperature difference calculationSubscripts |
| c | - | cold fluid (feedwater) |
| d | - | fluid from the previous heaters or other processes |
| h | - | hot fluid (steam) |

## I. INTRODUCTION

The heat recovery system has become an effective method to increase the thermal efficiency in modern thermal power plant [1]. The Feedwater heaters increase the Rankine cycle efficiency by raising the temperature of feed water that is piped into the steam generator, in such a way that the necessary thermal energy transferred to the steam to increase the enthalpy of the system will be lower.

In closed feedwater heater, the heat is transferred from the extracted steam of steam turbine to the feedwater heater without mixing taking place. The feedwater flows through the tubes in the heater and extracted steam condenses on the outside of the tubes in the shell. The heat released from the condensation is transferred to the feedwater through walls of the tubes. The condensate (saturated water at the steam extraction pressure) passes through a trap into the next lower pressure heater. This reduces the steam required by that heater. The trap passes only liquid and no vapour. The drip from the lowest pressure heater could similarly be trapped to the condenser, but this would be throwing away energy to the condenser cooling water. Fig 1 shows an example of three feedwater heaters connected in series.

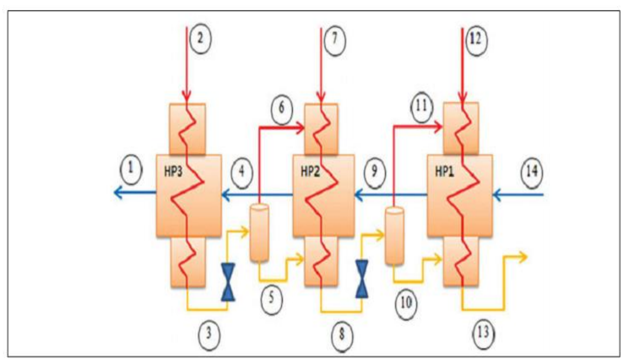


Fig 1: Feedwater Heater arrangement

Table 1: Explanation of numbers in Fig1

| No | Description | Feedwater heater |
|---|---|---|
| 1 | Feedwater outlet | 1,4,9&14 |
| 2 | Bleed steam inlet | 2,7&12 |
| 3 | Condensate outlet | 3,5,10&13 |
| 4 | Flash box condensate | 6&11 |

The heat transfer area in a feedwater heater is divided into three zones 1. Desuperheating 2. Condensing, 3.Drain cooling. Fig 2 shows general arrangement diagram of feedwater heater and fig 3 different zones of feedwater heat transfer area.

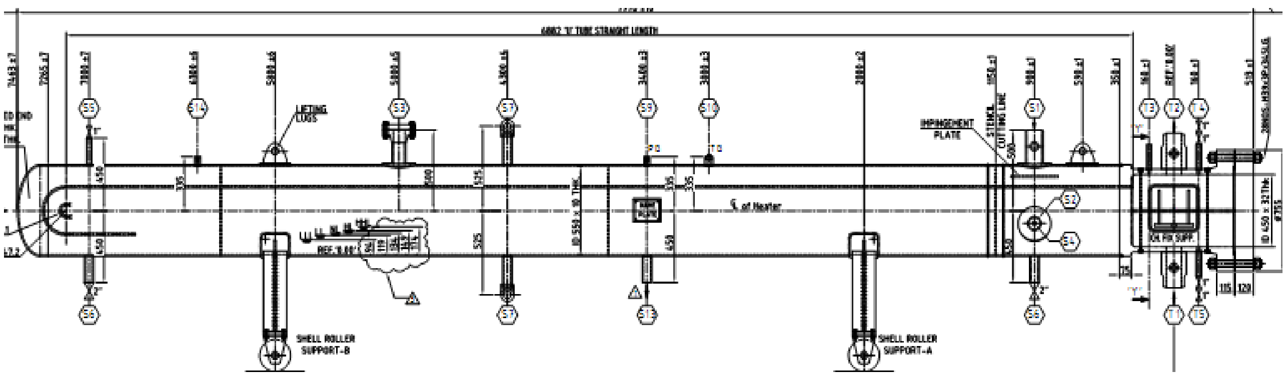

Fig 2: G.A of feedwater heater

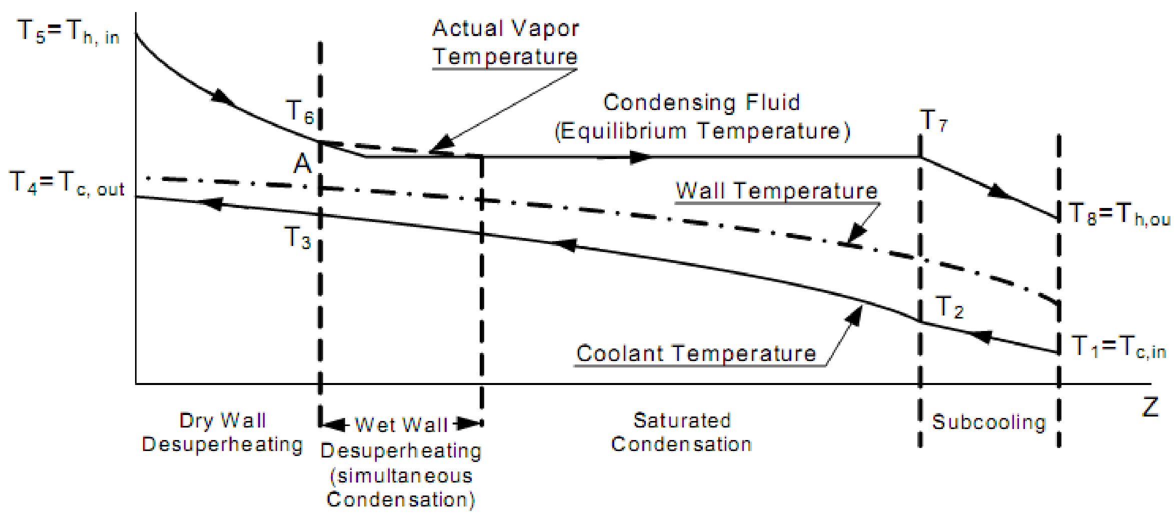


Fig 3: Different zones of feedwater heater

## II. GOVERNING EQUATIONS

Heat transfer in a feedwater heater can be formulated as:

$$Q = UAF\,\Delta tm \qquad (1)$$

Each feedwater heater zone will have an individual heat transfer value, Q , the sum of which will equal total heat transferred by the feedwater heater. It will also have an overall heat transfer coefficient, U, and a heat transfer surface area, A. The value of the logarithmic mean temperature difference (LMTD), Δtm, may be calculated for pure parallel flow or counter flow heat exchangers with the following equation [2] :

$$\Delta tm = \frac{GTTD - LTTD}{\ln (GTTD/LTTD)} \qquad (2)$$

where, the greater terminal temperature difference, GTTD, and the lesser terminal temperature difference, LTTD, are calculated [3] in parallel flow heaters by:

$$GTTD = t_{hi} - t_{ci}$$

$$LTTD = t_{ho} - t_{co}$$

and in counterflow heaters by:

$$GTTD = t_{hi} - t_{co}$$

$$LTTD = t_{ho} - t_{ci}$$

In Eq. (1), the correct factor, F, depends upon the particular flow arragment in shell-and-tubes heat exchangers [4].

In the case of nuclear power plants, the hot fluid inlet temperature, $t_{hi}$, is the saturation temperature at heater pressure; as this pressure is known by a pressure transmitter usually installed in the heater, the temperature can be calculated by using the IAPWS (International Association for the Properties of Water and Steam) formulation [5].

If Eq. (1) is resolved for a single zone (condensing) feedwater heater, all temperatures in the preceding equations will be known, and the value of the logarithmic log mean temperature difference, Δtm, may be easily calculated. However, the single zone design is not the normal design for power plant heaters with two or more zones (desuperheating, condensing and drain cooling). The intermediate temperatures of the cold fluid (feedwater) should therefore be calculated, as will be discussed later, by using an indirect procedure.

In Eq. (1), the heat transfer surface area, A, can be calculated from the geometry of the tubes, which are specifications that

will be supplied by the heater manufacturer. This value should be corrected, where tubes may have become plugged.

Finally, the overall heat transfer coefficient, U, is usually indicated by the manufacturer, but it should be noted that the value is greatly influenced by specific operating conditions.

$$\text{Heat rate} = \frac{\text{mass of steam} \times (\text{Steam outlet enthalpy} - \text{Feed water enthalpy})}{\text{Poweroutput}}$$

## III. TECHNICAL DESCRIPTION OF FEEDWATER HEATER

Feedwater heaters are shell-and-tube heat exchangers, U-tube type heaters, which perform the special function of recovering heat from turbine extraction steam by preheating the boiler feedwater. High-pressure feedwater heaters are located downstream of the high-pressure boiler feedwater pump whereas low-pressure feedwater heaters are located downstream of the condensate pump. The steam that is extracted from the turbine is in most case available at superheated state. Heat is extracted first by desuperheating the steam, then by condensing the steam to bring it to saturated liquid state and in most cases, by further subcooling it to a temperature below the saturation temperature. Fig 4 shows simplified scheme of piping and instrument diagram of feedwater heater.

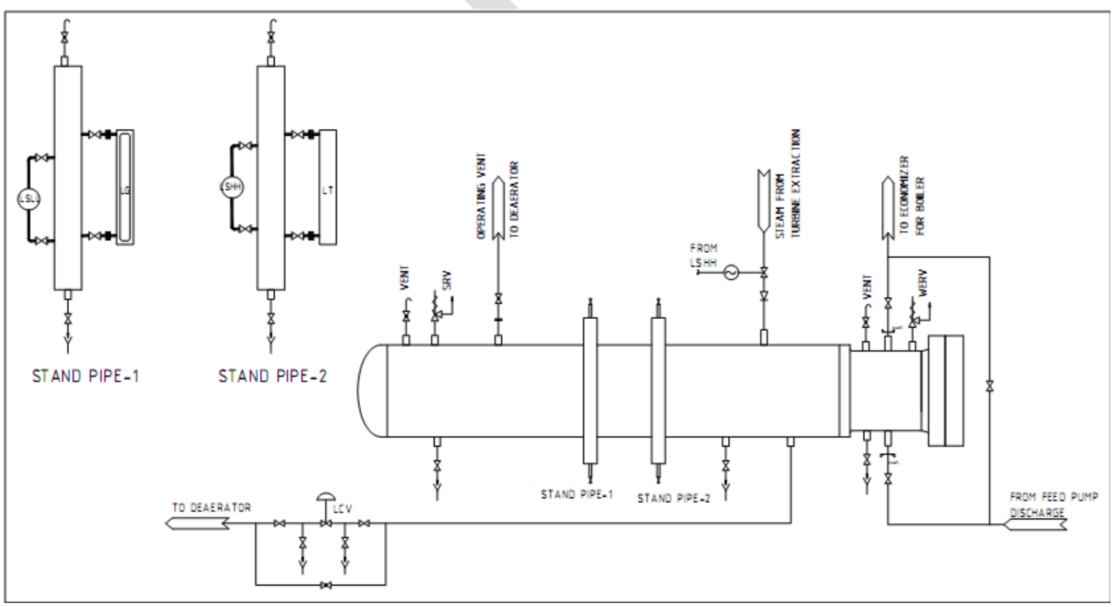


Fig 4: Piping and instrument diagram of feedwater heater

*3.1 Operational parameters of feedwater heater*

| Sl.No. | Description | Units | Shell side | Tube side |
|---|---|---|---|---|
| 1 | Medium | | SH steam | Feed water |
| 2 | Normal Flow | Tph | 10 | 116 |
| 3 | Enthalpy at inlet | Kcal/Kg | 730.91 | 155.58 |
| 4 | Enthalpy at outlet | Kcal/Kg | 160.34 | 205.11 |
| 5 | Temperature at inlet | Deg C | 311.4 | 153.1 |
| 6 | Temperature at outlet | Deg C | 158.9 | 200.7 |
| 7 | Pressure at inlet | bar g | 16.97 | 102 |
| 8 | Pressure at outlet | bar g | 16.40 | 101 |
| 9 | Maximum flow condition | Tph | 11 | 207.11 |
| 10 | Feed pump shut off pressure | Bar | - | 115 |
| 11 | Pressure drop allowed | Bar | 0.5 | 1 |
| 12 | Material of tube | | | SS 304 |
| 13 | No of passes | | | Two |
| 14 | Terminal temperature difference | Deg C | | 2.6 |
| 15 | Drain cooler approach | Deg C | | 5.5 |
| 16 | Corrosion allowance | mm | 3.2 | 3.2 |
| 17 | Radiography/Joint efficiency | | Full/1.0 | Full/1.0 |
| 18 | Code of design | | HEI/IBR/ASME | |
| 19 | Material of supports | | IS 2062 | |
| 20 | Material of shell/channel | | SA 515 Gr. 70 | |
| 21 | Bolts/nuts | | SA 193 Gr. B7 / 194 Gr. 2H | |
| 22 | Hydraulic test pressure | Bar | As per code | As per code |

## IV. RESULTS AND DISCUSSIONS

*4.1 Power plant cycle without feedwater heater*

Typical power plant, 30 MW capacity, has been analysed without feedwater heater arrangeemnt by using HMBD. The selected main steam parameters are 88 ata and 520 $^{0}$C. The required steam flow is 110.30 TPH to generate 30 MW power. The feedwater parameters at inlet condition of boiler are 100 ata,154.8 $^{0}$C and enthalpy of feedwater is 157.32 kcal/kg.

The coal requirement for the above condition is 26.17 TPH, considering GCV of fuel around 3500 kcal/kg.The turbine heat rate is 2425.15 kcal/kwh (without feedwater heater).

Considering the above all parameters, the overall power plant efficiency for without feedwater condition is 28.36%. The HMBD for without feedwater heater condition is shown fig 5 :

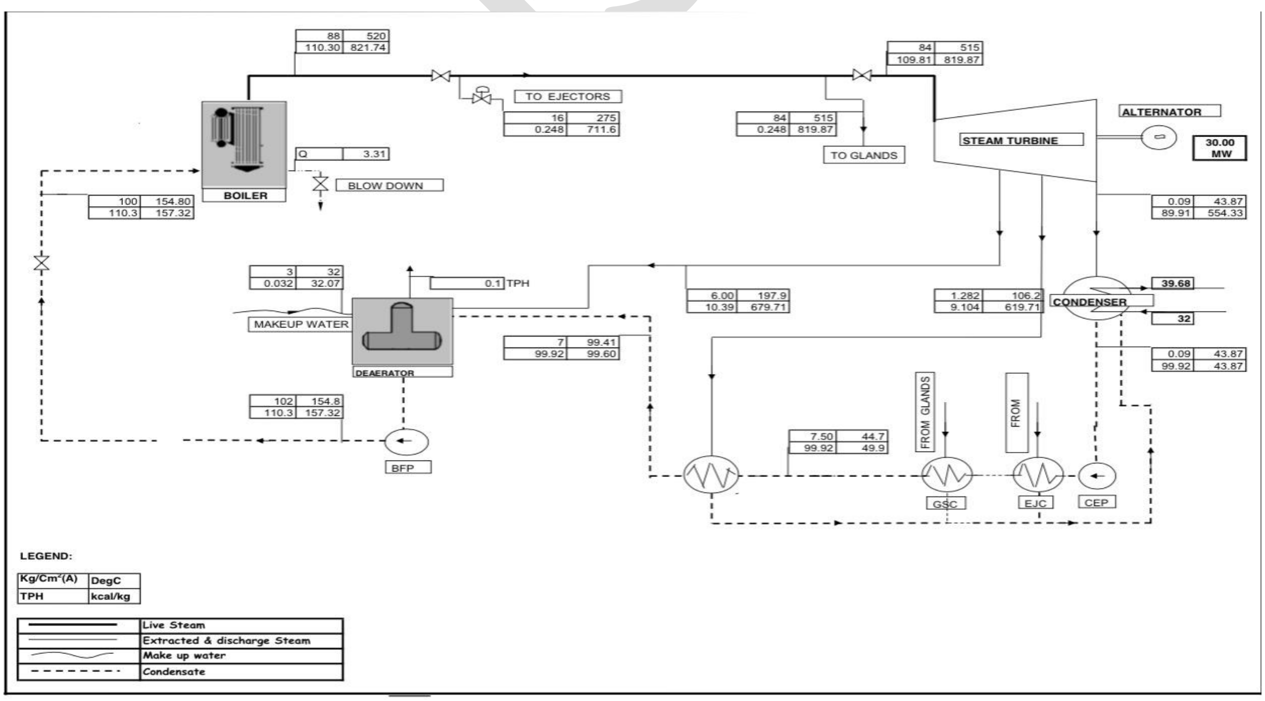


Fig 5: HMBD for without feedwater heater condition

*4.2 Power plant cycle with feedwater heater*

The same main steam parameters are (88 ata and 520 $^0$C) selected for above condition also. The required steam flow is 115.99 TPH to generate 30 MW power. The feedwater parameters at inlet condition of boiler are 100 ata, 200.7 $^0$C and enthalpy of feedwater is 205.11 kcal/kg.

The coal requirement for the above condition is 25.5 TPH, considering GCV of fuel around 3500 kcal/kg.The turbine heat rate is 2366.12 kcal/kwh (with feedwater heater).

Considering the above all parameters, the overall power plant efficiency for with feedwater condition is 29.07%. The HMBD for with feedwater heater condition is shown fig 6:

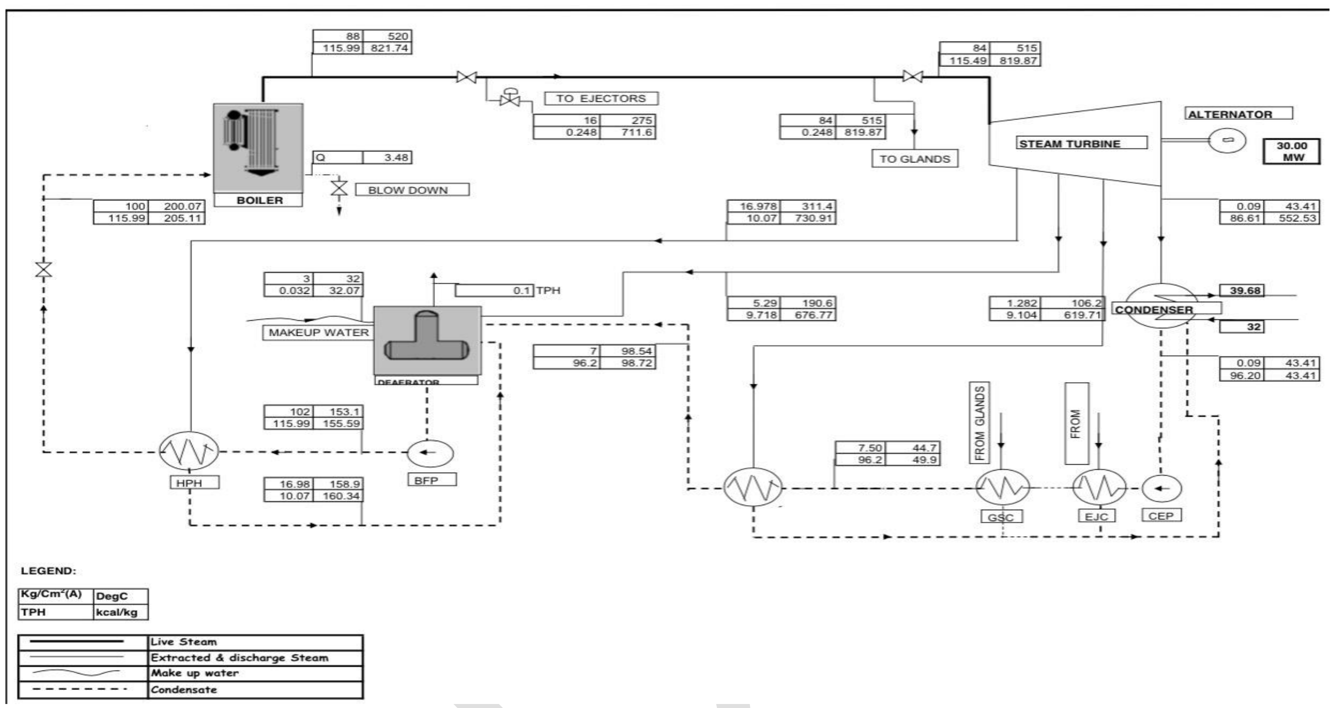


Fig 6: HMBD for with feedwater heater condition

## V. CONCLUSION

The effects of the feedwater heaters on the performance of coal-fired power plant have been determined through analysis of using HMBD. An analysis reveals that overall power plant efficiency has been increased by 2.4 % using feedwater heater. The turbine heat rate and coal consumption have been considerably decreased. This implies a direct reduction $CO_2$ emission. The final result shows an overall better performance of power plant by using feedwater heaters.

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