

# PERFORMANCE ANALYSIS AND OFF DESIGN BEHAVIOUR OF FEED WATER HEATER

Khub Chand Kushwaha<sup>1</sup>, Bhupendra Koshti<sup>2</sup>

<sup>1</sup>*Khub chand Kushwaha, E-mail kckushwaha08@gmail.com*

<sup>2</sup>*Bhupendra Koshti, E-mail Bhupendrakoshti.bk@gmail.com*

*Department of Mechanical Engineering People's University, Bhopal, India*

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## Abstract

A power plant has several utilities and all working in together to meet ever increasing demand of power in efficient way. Off design conditions occur on several occasions in steam power plant. These can occur because of the low load on the power plant and unavailability of some components. Under these conditions the design operating parameters are changed.

This paper describes the various conditions which leads feed water heater to work under off design conditions, which changes its performance and effectiveness. This paper also discusses the behavior of feed water heater under these conditions of operation.

**Keywords:** Feed water heater, Steam, off-design conditions, Temperature, Feed water.

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## 1. Introduction

### 1.1 Feed water heater

A Feed-water heater is a power plant component used to pre-heat water delivered to a steam generating boiler. A practical Regeneration process in steam power plants is accomplished by extracting or bleeding, steam from the turbine at various points. This steam, which could have produced more work by expanding further in the turbine, is used to heat the feed water instead. The device where the feed water is heated by regeneration is called Regenerator or a Feed water Heater. A feed water heater is basically a heat exchanger where heat is transferred from the steam to the feed water either by mixing the two streams (open feed water heaters) or without mixing them (closed feed water heaters).

### 1.2 Open Feed water Heaters

An open feed water heater is basically a mixing chamber, where the steam extracted from the turbine mixes with the feed water exiting the pump. Ideally, the mixture leaves the heater as a saturated liquid at the heater pressure. The advantages of open heater are simplicity, lower cost, and high heat transfer capacity. The disadvantage is the necessity of a pump at each heater to handle the large feed water stream.

### 1.3 Closed Feed water Heaters

In closed feed water heater, the heat is transferred from the extracted steam to the feed water without mixing taking place. The feed water 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 feed water through the walls of the tubes. The condensate (saturated water at the steam extraction pressure), sometimes called the heater-drip, then passes through a trap into the next lower pressure heater. To some extent, this reduces the steam required by that heater. The trap passes only liquid and no vapours. 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. To avoid this waste the drip pump feed the drip directly into the feed water stream.

A closed heaters system requires only a single pump for the main feed water stream despite of the number of heaters. Closed heaters are costly and may not give as high a feed water temperature as give with open heaters. In most steam power plants, closed heaters are preferred, but at least one open heater is used for the purpose of feed water de-aeration. The open heater in such a system is called de-aerator.

A feed water heater is a heat exchanger designed to preheat boiler feed water by means of condensing steam extracted from a steam turbine. The heaters discussed in this paper are classified as closed, since the tube side fluid remains enclosed by the tubes and channel, and does not mix with the condensate, as is the case with open feed water heaters. They are unfired since the heat transfer within the vessel does not occur by means of combustion, but by convection and condensation.

The steam extraction process in closed feed water is referred to as uncontrolled extraction. The flow rate of steam into a feed water heater is not limited by the amount of available steam. The shell side operating pressure in a feed water heater is determined by the pressure of the steam supplied to it, not by the amount of heat transfer surface.

#### ***1.4 Relation to Power Plant Cycle***

The heating process by means of extraction steam is referred to as being regenerative. The feed water heaters are an integral portion of the power plant thermodynamic cycle. Generally, there are several stages of feed water heating. Each stage corresponds to a turbine extraction point. These extraction points occur at various stages of the expansion of steam through the turbines. The presence of the heaters in the cycle increases the thermal efficiency of the power plant. The greater the number of extraction stages, the lower the amount of thermal energy required to generate a given amount of electrical energy. The energy extracted by the heaters reduces the rate of rejection of energy to the environment.

#### ***1.5 Pressure Classification:***

**Low Pressure Heater**-Low pressure heaters are placed between the main condensate pumps and the boiler feed water pumps and consist of a U-Tube bundle heat exchanger mounted in a tube sheet and surrounded by a steam shell. Stainless steel is often used to protect against corrosion and erosion while longitudinal welding allows thin tube walls to be produced. It normally extracts steam from the low pressure turbine.

**High Pressure Heater:** These are placed between the boiler feed water pump and the boiler. The tube material varies depending on your nuclear power plant's needs, although the standard is a seamless low alloy carbon steel. This provides good thermal conductivity as well as good mechanical properties at high temperatures.

#### ***1.6 Zones***

Zones are separate areas within the shell in a feed water heater. various zone show in figure1 -

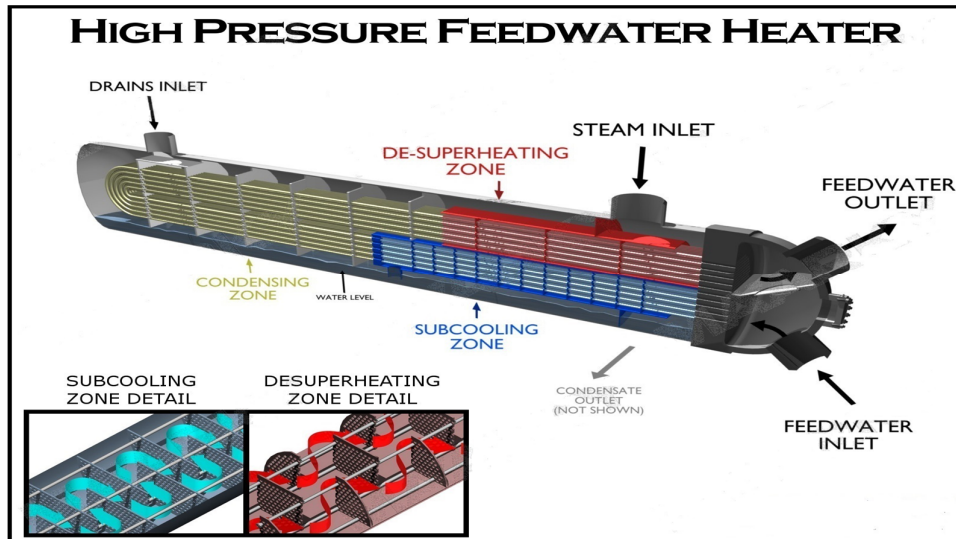


Figure 1. Different Zones Feed water Heater

**Condensing Zone:** All feed waters have this zone. All of the steam is condensed in this area, and any remaining non condensable gases must be removed. A large percentage of the energy added by the heater occurs here.

**Sub-cooling Zone:** The condensed steam enters this zone at the saturation temperature and is cooled by convective heat transfer from the incoming feed water.

**De-superheating Zone:** The incoming steam enters this zone, giving up most of its superheat to the feed water exiting from the heater.

## 2. RELATED WORK

Syed M.Zubair, M.A Antar et al. [6], proposed a numerical method of analyzing closed system feed water heaters. The numerical results are validated using data generated from the classical log mean temperature difference (LMTD) method. It is found that the numerical results are very close ( $\pm 1\%$ ) to the ones predicted by the LMTD method. Temperature and heat transfer distributions along the length of the heat exchanger are presented. A general approach to determine area allocations among the de-superheating, condensing and sub cooling zones under a known set of operating conditions is presented for a feed water heater in a steam power plant. It is shown through an example problem that a significant amount of heat duty (about 80%) is handled by the condensing zone, whereas the sub cooling zone handles the least amount of heat duty.

Farhad et al. [7], conducted an experimental study on integrated design of all feed water heaters using pinch technology and energy analysis by taking the effect of the enthalpy rise of the feed water passing through the pumps and the effects of this method on other components of the steam cycle. They found that by applying this method with target pinch temperature of  $3^{\circ}\text{C}$ , the fuel consumption decreases, the load on condenser decreases, the boiler exergetic efficiency increases. In feed water heater the irreversibility involved in heat transfer decreases, thus efficiency of feed water heater increases, and turbine exergetic efficiency increases with decreasing relative pinch temperature. Thus this design method decreases the energy destruction in the feed water heaters network as well as in boiler, turbine and condenser. Hence, the increase of the cycle efficiency is due to the improvement of the efficiency of all the mentioned components.

Cheng et al. [8] conducted an experimental study to determine the effect of drain outlet temperature on turbine heat rate and performance of horizontal closed feed water heater. They found that a higher liquid level in drain cooler heater section cause more submerged feed water tubes and decrease the heat transfer coefficient. On the other hand if level of liquid is too low, the heater drain cooler tends to be directly exposed to the high velocity and high temperature steam and susceptible to damage. They also found that the heater drain temperature affects turbine heat rate only when significant de-superheat spray flow exists. They have been efforts to improve the performance of HP feed water heater by optimizing individual feed water heater level set point. They concluded that when the spray flow does exist, which is offer the case of the power plant routine operation, the total energy gain in the heater train can be improve by decreasing the water enthalpy at last HP feed water heater drain outlet. One possible way to achieve this goal is to manipulate all heater drain levels at low end of their allowable ranges.

Antar Mohamed A, Zubair Syed M.et al. [12] proposed a numerical method for analyzing closed system feed water heaters. A general approach to determine area allocations among the de-superheating, condensing and sub-cooling zones under a known set of operating conditions is presented for a feed water heater in a steam power plant. A significant amount of heat duty is handled by the condensing zone, whereas the sub-cooling zone handles a least amount of heat duty which essentially vanishes at low steam pressures. Fluids mass flow rates and accordingly the overall heat transfer coefficients have significant effects on the areas needed for de-superheating, condensing and sub-cooling in a feed water heater. Two fouling models are considered to examine their effect on the heat exchanger performance. Insignificant changes were noticed when comparing the heat transfer rate and outlet temperature results of both the models. It is found that heat duty of the heat exchanger decreases by 2.7% in 3years when we use the recommended fouling resistance, while the outlet shell-side fluid temperature increased by 6.3%.

Becker Bryan R., Pearce Richard E.et al. [10], this paper describes the methodology of life management and its application to feed water heaters at Kansas City Power and Light. This paper describe a physical condition assessment is the first step in a life evaluation. The second step in a life evaluation is an economic life assessment to ascertain the component's current loss of performance and projected life. The cost associated with operating the component in its current degraded state is then compared to the cost of repairing or replacing the component. Based on this cost comparison, a course of action is determined to optimize the component's life cycle cost.

Jan T. Szargut et al. [13], showed the influence of particular regenerative feed-water heaters on the operational costs of a steam power plant and HP plant has been determined by means of the incremental energy efficiency expressing the ratio of the increase of electricity production to the increase of the consumption of chemical energy of fuel, assuming a constant flow rate of steam at the outlet of the turbine (power plant) or a given production rate of useful heat.

### **3. PROPOSED METHODOLOGY**

A feed water heater is designed for fixed operating conditions, in which it is most effective and leads to maximum efficiency for the power plant. Due to change in the operating conditions like plant operating under partial load or due to failure of any turbine stage or feed water heater, the plant often operates under off-design conditions and the operating parameters for the feed water heater changed under these conditions.

Due to the change in the operating conditions, the fractional area occupied by different zones will be redistributed. The behavior of a High Pressure feed water heater under different conditions of operation by using LMTD method is analyzed. We are found the distribution of fractional area of different zones of HP feed water heater and exit temperature profile of drain and feed water.

### **4. PERFORMANCE EVALUATION**

The feed water heater performance is evaluated by the following parameters:

1. Terminal temperature difference (TTD) across the heater

$$TTD_{fwh} = T_{s2} - T_{t1} \quad (1)$$

The TTD is essentially a measure of the heat transfer capability of the feed water heater. The higher the TTD

above the design value, the poorer performance of the heater.

2. Temperature gain across the heater ( $\Delta T_{fwh}$ )

$$\Delta T_{fwh} = T_{t1} - T_{t4} \quad (2)$$

3. Drain cooler approach (DCA)

$$DCA = T_{s4} - T_{t4} \quad (3)$$

The efficiency of feed water heater increases and surface area of feed water heater required for given HT increases, with decreasing the value of TTD and DCA. Therefore the fuel consumption reduces and capital cost of feed water heater increases by reducing TTD and DCA.

4. Feed water heater efficiency ( $\eta$ )

$$\eta = \frac{\text{Heat gained by feedwater in the heater}}{\text{Heat in steam extracted into the heater}} \quad (4)$$

### 5. RESULT ANALYSIS

The mass flow rate of steam vary when plants operates at off-design condition. In a feed water heater, there are no control valves on the extraction steam supply lines. Steam flow adjusts itself by a thermal equilibrium process.

**Table 1. Results from LMTD method with changes in mass flow rate of steam**

$M_s$ (kg/s)	% of $A_1$	% of $A_2$	% of $A_3$
7.56	34.17	63.96	1.9
7.2	31.2	59.14	9.66
6.87	28.76	55.23	16.00
6.3	22.73	42.38	34.9
6.18	22.20	41.73	36.07
5.5	17.43	32.14	50.43

**Table 2. Results from LMTD method with changes temperature**

$M_s$ (kg/s)	Q(kJ/s)	$T_{t1}$ (°C)	$T_{t2}$ (°C)	$T_{t3}$ (°C)	$T_{s4}$ (°C)
7.56	16373.8	237.23	230.82	196.95	227.20

7.2	16215.4	236.35	230.25	197.98	208.46
6.87	15677.7	235.55	229.73	198.95	201.97
6.3	14542.3	232.17	226.83	198.6	196.26
6.18	14253	231.98	226.74	199.05	196.7
5.5	12692.3	228.09	223.43	198.8	196.4

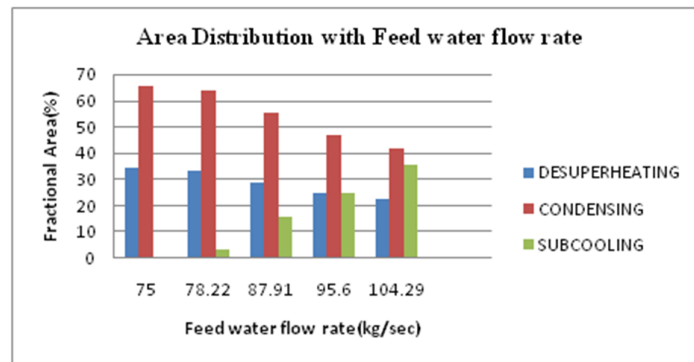


Figure 2. Variation of zonal are distribution with feed water

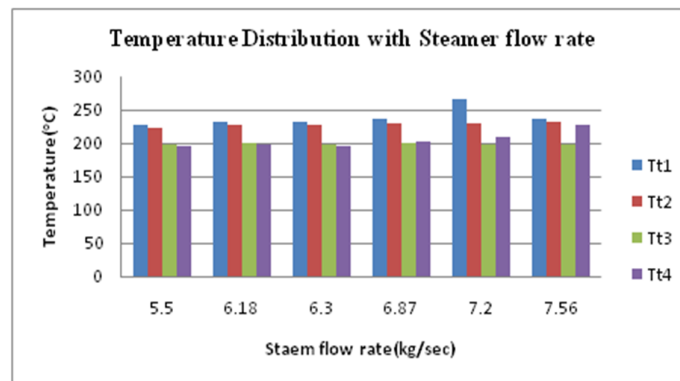


Figure 3. Variation of temperature distribution with Steam flow rater

In Figure 2 fractional area has been plotted against mass flow rate of steam. It is observed that fractional area of the de-superheating and condensing zone increases as flow rate of steam increases.

Figure 3 is a plot of  $T_{t1}$ ,  $T_{t2}$ ,  $T_{t3}$ ,  $T_{t4}$  and  $Q$  Vs mass flow rate of steam. It is observed that heat transfer rate and exit temperature of steam increases with flow rate of steam.

### 6. CONCLUSION

Fractional areas of de-superheating and condensing zone are almost directly proportional to mass flow rate of steam and inversely proportional to mass flow rate of feed water. Opposite is true for the drain cooling section. The changes in steam temperature, however do not appears to have a significant effect on the area

distributions. A change in exit temperature of feed water is small for all the given cases of off design conditions. Heat transfer rate increases with increasing the mass flow rate of feed water or steam.

### **7. FUTURE WORK**

The analysis can be improved by removing or relaxing these assumptions. The effect of part load and off design conditions will be evaluated further by simultaneous changing of more than one parameter. In this paper the influence of only one parameter is considered. The effect of pressure drop on shell and tube side will be taken on further analysis. The same analysis will be done for low pressure and deaerator feed water heater.

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### **A Brief Author Biography**

*1<sup>st</sup> Author Name - Khub Chand Kushwaha, PG Scholar*, Perusing M.Tech from People's University, Bhopal, India

*2<sup>nd</sup> Author Name - Bhupendra Koshti*, Assistant professor, Department of Mechanical Engineering, People's University, Bhopal, India.