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Performance Analysis of Regenerative Feed Heating System in Steam Power Plant

Dr M Ramakotaiah[1]
[1]*Department of Mechanical Engineering Ellenki College Of Engineering and Technology Patelguda, Hyderabad. Pin Code-502319*

***Abstract*: The development of any country directly relates on capital energy consumption. The demand for power generation on the large scale is increasing day by day. Owing to their major contribution towards power production, thermal plants have a vital role to play in the development of nation. Due to the scarcity of power, every power plant needs to be operated at maximum level of efficiency; particularly in case of thermal power plants this applies equally to all its auxiliaries.**

In the thermal plants, the feed water heaters from a part of the regenerative system to increase the overall thermal efficiency of the plant. In the operation and maintenance of a power plant, the feed water heaters are virtually neglected compared with other components. Efficient and reliable service of feed water heaters requires more care in both operations and maintenance than the care that has been taken in practice.

In the present work, those parameters which directly or indirectly influence the performance of a heater have been studied. The factors such has inlet temperatures, saturation temperatures, Terminal Temperatures, Difference, Drain cool Approach, and Temperature Rise are calculated. The data for the performance test and the subsequent calculations are collected from HP Heaters of UNIT – I, Dr: NTTPS.3

This dissertation work covers the study of operation and performance of various types of feed water heaters used in thermal power plant which will improve the cycle efficiency.

***Keywords*: Thermal, Fem, Thermo Dyanamics, Fm & Hm**

I. INTRODUCTION

A. Working Of the Thermal Plant

Outline of a thermal power station is shown in finger each unit consists of one boiler, one turbine and one generator. Coal is transported to the plant from mines by means of rail transport. The huge boulders of coal are crushed into small pieces and are supplied to the mills through conveyor system. In the mill these coal pieces are pulverized to fine powder. Hot air, which is called as primary air, is supplied to the mill to absorb moisture in the coal powder and transmits coal powder into the boiler. The primary air is supplied by using primary air fans. Coal powder ignites in the boiler and the chemical energy present in the coal is converted into heat energy. In order to ensure proper and complete combustion secondary air is supplied through the forced draught fans. Water from Boiler feed pumps circulates in the water wall tubes that are located inside the boiler. The heat energy is transmitted by means of convection and radiation principles and water in the water wall tubes is converted into steam by absorbing heat energy. The produced steam temperature and pressure are around 540 oC and 160Kgs/sqcm.

Steam generated in the boiler is supplied to the turbine. In the turbine heat energy is converted into mechanical energy using Rankin cycle and steam expands and condenses in the condenser. The condensed water will be-heated and supplied to the boiler using boiler feed pump, turbine is coupled to the generator and in generator mechanical energy is converted into electrical energy.

In boilers, after combustion of coal ash and glue gases are formed and they were evacuated using induced Draught Fans (ID Fans). The temperature of the flue gases is around 800 OC. These high temperatures ion flue gases are further absorbed by pre-heating water, primary air and secondary air. In order to avoid ecological problems glue gases along with ash are passed through electro static precipitators where ash is filtered and glue gases at around 130 OC are liberated into atmosphere. To accomplish this, one unit consists of a number of sub systems.

B. Technical data of 210mw turbines

1)	Main steam pressure	:	150kg/cm2
2)	Main steam temperature	:	535 OC
3)	Reheat steam temperature	:	5350 OC
4)	Full load steam flow	:	641 t/Hr
5)	Back pressure range	:	0.03 Ata to 0.12 Ata

6) No. of extractions : 6
7) Last stage blade height : 661.175m
8) Overall : 16.175m
9) Width : 10.6m
10) Weight of turbines : 480 tones
11) Frequency band : 47.5 to 51.5

B. Coal Handling Plante

In this plant coal is received from mines by rakes. The huge coal boulders are crushed into small pieces in the crushers. These pieces are supplied to mills.

C. Mills

In the mills the lumped coal pieces are crushed into fine powder. There are two types of mills. They are:

1) Bowl mills
2) Ball mills The bowl mill is one of the most advanced design of coal pulverizes, presently manufactured by M/S BHEL. The advantages are:
3) Low power consumption
4) Reliability
5) Minimum Maintenance
6) Quietest and vibration less operation

Types of raw coal mills in stage – 1, VTPS are of XRP – 783 (6 number per init). Power consumption is 300 to 340 KW and capacity is 34 tonnes per hour per one mill.

In ball mills, Nichrome balls are used to pulverize the coal. The hot primary air is supplied to the mill, which heats the coal powder and lifts the coal powder into the furnace.

D. Re-Crculation of Water

The water from the hot well passes through the low-pressure heaters (L.P.H) by the condensate extraction pumps (C E P). The water at the outlet of CEP has a temperature of 45 OC and a pressure of 18.4 kg/cm2. The water from C P is passed through a series of three L.P heaters. The tapped (bleed) steam from L.P turbine is used to increase the temperature of water. The tapped (bleed) steam from L.P turbine is used to increase the temperature of water. The steam, tapped in L.P heaters, is called extraction steam and has a temperature of 62.5O and a pressure of – 0. Kg/cm2. The water at the outlet of the L.P.H.1 has a temperature of 62.3OC having a temperature gain 25OC and is fed to the L.P.H.2.

The tapped steam for L.P.H.2 has a temperature of 107OC and pressure of – 0.2 kg/cm2. The temperature of water at outlet of L.P.H.3 has a temperature of 119.6OC and the gain in each L.P.H.2 and L.P.H.3. Is 30OC.

From the L.P. heaters, the water goes to the de-aerator, where the dissolved oxygen is removed, so as to avoid the reaction of oxygen with the pipes. For de-aeration, steam from I.P turbine is tapped which has a temperature of 316 OC with a pressure of 7.2 kg/cm2. In de-aerator the water is sterilized by the steam: so that the dissolved oxygen flames are go away. Here also the water gains some temperature pressure of water, stored in feed storage tank, is 164O C and 7.2 kg/cm2 respectively the stored water is fed to the booster pumps. The pressure of discharged water at the booster pump is 16 kg/cm2. The discharge of the booster pump is sucked in to the boiler feed pump. There are three B.F.P,s in which one is standing by. B.F.P. discharge has a temperature of 175OC and a pressure of 181.9 kg/cm.2. The water from B.F.P. is passed through the high pressure heaters i.e. H.P.P-5 and H.P.P-5 and H.P.H-6.

The steam for HP heaters is tapped from the cold re-heaters to heat the feed water, which has a temperature of 343OC and pressure of 40 kg/cm2 the temperature of water at the outlet of H.P.H-6 is 235 OC with a pressure of 180 kg/cm2. Now the feed water is passed through the feed regulating system. Now the water is sent to the boiler drum through the economizer.

In economizer, water is heated by using the heat energy of flue gases obtained from the furnace. The temperature of economizer outlet is 297.3 OC. the hot water is fed to the boiler drum. The super-heaters removes any moisture present in the saturated steam. The steam at outlet of the super heater has a temperature of 540 OC and a pressure of 150 kg/cm2. The steam at this temperature is sent to the HP turbine and this process goes like a cycle.

E. Bearings

The bearings are made into two halves and are elliptical in type. The HP rotor is supported by two bearings. The LP and IP rotors have a journal bearing each at the end of their shafts. These are self-adjusting bearings. The bearing of the HP rotor are with spherical support with surface contacts. The IP and LP bearings have line contact on the spherical supports obtained with help of tours pieces. Bearing Babbitt temperatures are measured by the thrust pads is measured by the thermocouples directly under the white metal. The temperature of the thrust pads is measured by the thermo couples in two opposite pads on both turbine sides and generator side. Lube oil is admitted in the oil spaces that are milled into the baring shells at the horizontal joint and are open to the shaft journal. All the bearing is provided with jacking oil facility at 120 kg/cm2.

F. Different component of steam power plant:

1) Boiler
2) Super haters
3) Turbine
4) Re-heater
5) Condenser
6) Boiler feed pumps
7) Economizer
8) Air-preheated
9) De-aerator

G. Boiler

Boiler may be defined as a closed vessel, in which steam is produced from water by combustion of fuel. It is also called as steam generator; the boiler used in this thermal power station is a water tube boiler. In this boiler the coal is fed into the boiler from four sides at four different angles, such that a round flame is obtained. The coal is ignited initially by using oil guns. The steam generated in the boiler is at temperature of 340 OC. The waste coming from steam boiler is ash and exhaust gases. The saturated steam is passed through the super-heaters. It raised the temperature of the steam up to 540 OC and pressure to 150 kg/cm2.

H. Superheater

A super hater is a device used to convert saturated steam or wet steam into dry steam used for power generation or processes. There are three types of super heaters namely: radiant, convection, and separately fired. A super heater can vary in size from a few tens of feet to several hundred feet (a few meters or some hundred meters).

Fossil fuel power plants can have a super heater and/or re-heater section in the steam generating furnace. Nuclear-powered steam plants do not have such section but produce steam at essentially saturated conditions. In a fossil fuel plant, after the steam is conditioned by the drying equipment inside the steam drum, It is piped from the upper drum area into tubes inside an area of the furnace known as the super heater which has an elaborate set up of tubing where the steam vapor picks up more energy from hot flue gases outside the tubing and its temperature is now superheated above the saturation temperature. The superheated steam is than piped through the main steam lines to the valves before the high pressure turbine.

The turbines used in V.T.P.S are of condensing. Reheat and regenerating type, tandem compounded (supporting), three cylinder and horizontal type, with throttle governing, coupled to an A.C generator.

Basic Principles of Steam Turbine Operation:

1) Conversion of heat energy into kinetic energy.
2) Operation depends on dynamic action of steam
3) Drop in steam pressure and change in velocity, in direction of motion giving rise to change in momentum, which is the driving force of prime mover.

I. Hp Turbine

H.P. (high pressure) turbine is a single flow cylinder, built in stage of blades as 1*25. This is governed by throttle control. It also permits flexibility of operation in the form of short start-up times and high rate of change of load even at high initial steam condition. The blades of all stage are reaction type, with 50% efficiency. It has double wedge journal bearing front end and thrust bearings at rear end, coupled to I.P. rotor, rigid coupling are used connection the H.P. and I.P rotors.

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The outer casing is of barrel type construction. This avoids mass accumulation due to absence of flanges. As a result of almost complete rotational symmetry the wall thickness is kept moderate and of nearly equal strength at all section, the inner casing carries the guide blades and is axially split and kinematical supported. The space between the inner casings is not supported to large pressure drops the joint flange and bolts are designed for less stringent conditions. The inner casing is fixed in the horizontal and vertical planes in the outer casing so that it can freely expand radically in all directions and axially from a fixed point when heating up while maintaining eccentricity. The barrel construction permits rapid start up and higher rates of load changes due to absence of thermal stresses. Barrel type casings are also easy to cast which means the castings can be of exceptionally good quality.

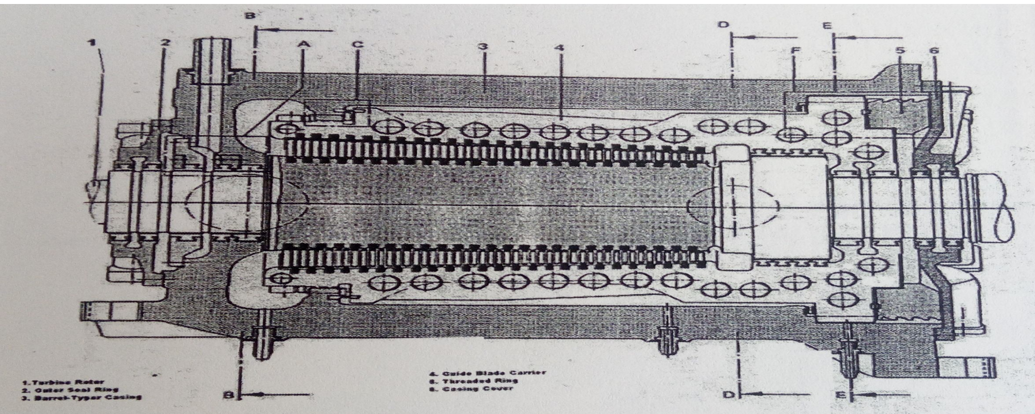
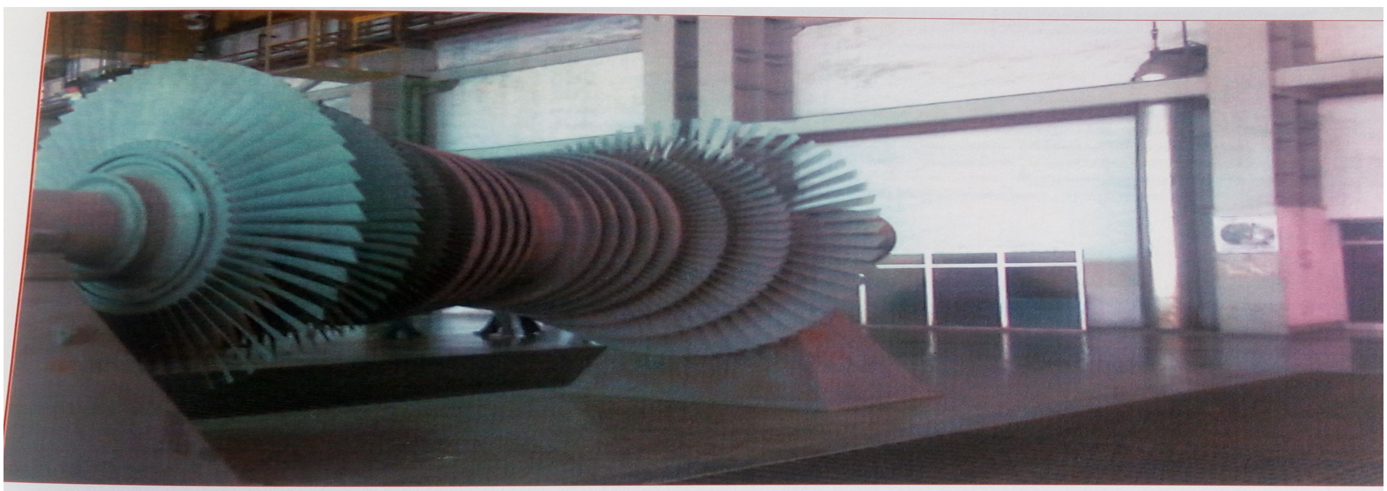


Fig1.4.3 a: HP Turbines



H.P.TURBINE

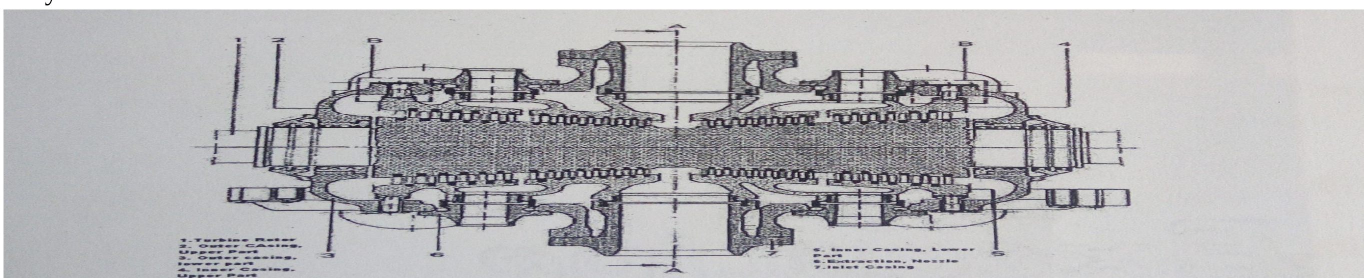
J. Ip turbine

I.P (Intermediate pressure turbine is a double flow cylinder type and blades are in stage 2*20(2pass, stages) the construction of I.P turbine is same as H.P. turbine steam from H.P turbine. After reheating, entre into the inner casing from the above and below, through inlet nozzles, flanged to the middle section of the outer casing. This arrangement provides opposed double flow in the 2-bload section and compensates axial thrust; all stages are 50% reaction. It has journal bearing at the end of the shaft.

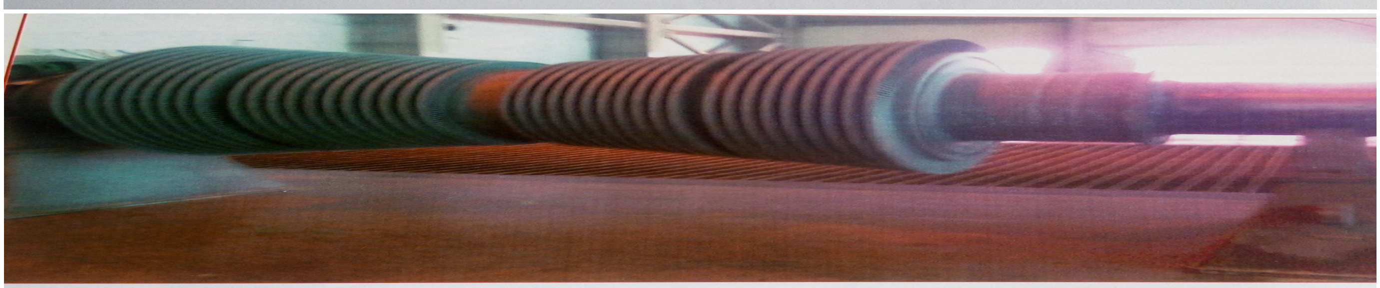
The L.P casing is split horizontally and is of double shell and double flow construction, with the inner casing. Carrying the guide blades and cinematically supported within the outer casing. The construction provides flexibility for choosing the location of bleed steam point to suit the best thermal efficiency. The reheated steam enters inner casing through top and bottom. The arrangement confines the high steam temperature to the admission branch of the casing while the joint of the outer casing in only subjected to lower pressure and temperature at the exhaust of the inner casing. Although the casing are of split design yet not impose restriction in start-up timings and rapid load changes due to provision of suitable stress relieving grooves built in the inner casing. The hydraulic turning gear blades are located on the coupling of the IP rotor.

L.P (low pressure) turbine consists of double flow unit and has a triple shell welded casing. The blades are in the three stages of 2*8(2passes, 8 stages). Steam is admitted into the L.P turbine is from the I.P turbine form both sides though. Steam inlet nozzles I.P turbine is also a reaction type; the stationary blades of first stage have T-roots are inverted in corresponding design in L.P. turbine shaft and secure by caulking material. Slots are provided on the design in L.P turbine shaft and secure by caulking material. Slots are provided on the blade surface of last Stationary row. Through these slots any water passing on the blade surface of the blades may be drawn away to the condenser. The journal bearing is situated in the L.P turbine and generator.

The L.P casing is of triple shell fabricated construction. The outer casing consists of the front and rear end walls. The twin shell inner casing is supported cinematically at each end by two supporting arms resting on the side members of the Outer casing. The inner shell if the inner casing the guide blade carrier of the first of the turbine. Rings of the guide blade carries, which constitute the remaining Stages of the turbine, are bolted to the middle inner outer casing. The L.P turbine is provided with exhaust – hood spray facility.



IP Turbines



I.P.TURBINE

K. Reheater

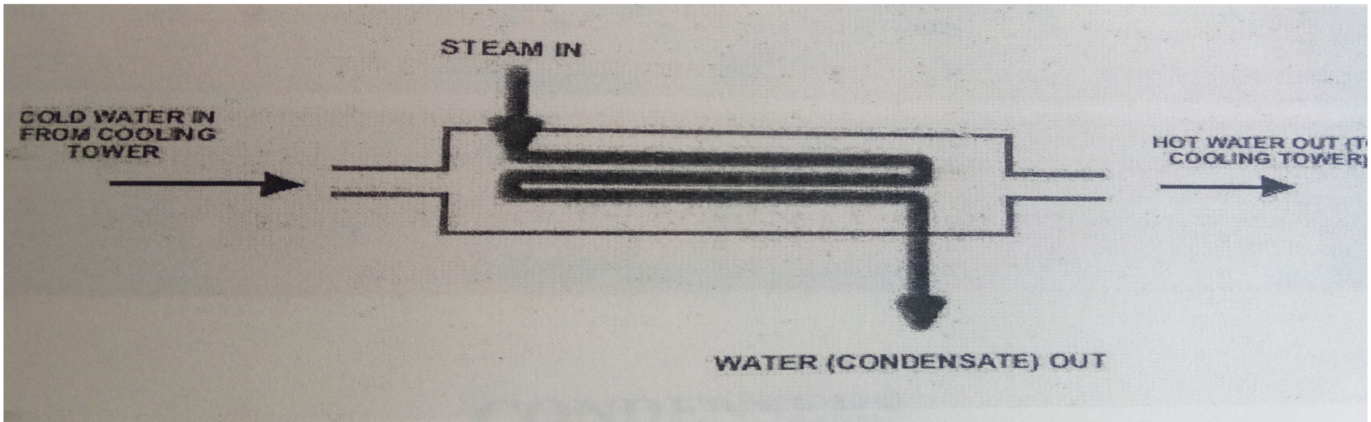
Power plant furnaces may have reheater section containing tubes heated by hot flue gases outside the tubes. Exhaust steam from the high pressure turbine pressure turbine is rerouted to go inside to go inside the reheater tubes to pick up more energy to go drive intermediate or lower pressure turbine. This is what is called as thermal power.

The surface condenser is a shell and tube heat exchanger in which cooling water is circulated through the tubes. The exhaust steam from the low pressure turbine enters the shell where it is cooled and converted to condenser (water) by flowing over the tubes as show in the adjacent diagram. Such condensers use steam ejectors or rotary motor-driven exhauster for continuous removal of air and gases from the steam side to maintain vacuum

L. Condenser

After expansion in the turbine, steam loses its temperature and enters condenser. In the condenser steam falls on tubes in which cold water is circulating and Steam gets condensed. This condensed water is supplied to the boiler by means of boiler feed pumps.

In addition to the above equipment there are other system also functioning like ash handling system for disposal of ash, circulation water plant for supply of water to the plant, treatment plant for water chemistry etc.

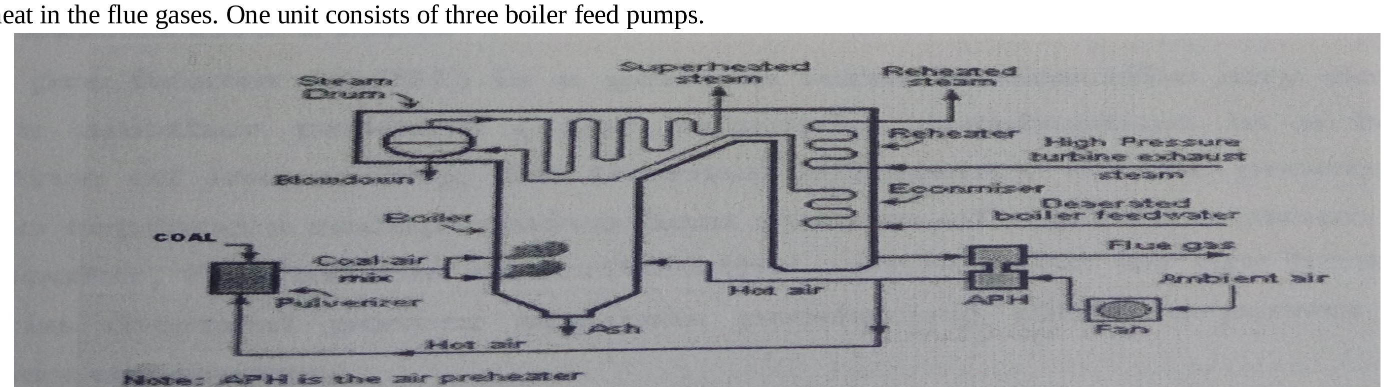


Functional arrangement of a power plant condenser

CONDENSERS

M. Boiler feed Pump

A boiler feed water pump is a specific type of pump used to pump feed water into a steam boiler. The water may be freshly supplied or returning condensate produced as a result of the condensation of the steam produced by the boiler. These pump are normally high pressure units that use suction from a condensate return system and can be of the centrifugal pump type or positive displacement type. It is variable speed driven pump. It supplies pre-heated water to boiler. Water is pre-heated in economizer utilizing the wasted heat in the flue gases. One unit consists of three boiler feed pumps.



Boiler feed pump

II. EFFETED OF OPERATING CONDITIONS ON RANKING CYCLE EFFICEENCY:

A. The Rankin cycle efficiency can be improved b

1) *Increasing boiler pressure:*It has been observed that by increasing the boiler pressure (other factors remaining same) the cycle tends to rise and reaches a maximum value at boiler pressure of about 166 bars.
2) *Superheating:*All other factors remaining the same, if the steam is superheated before allowing it to expanding the Rankin cycle efficiency may be increased. The use of superheated steam also ensures longer turbine blade life because of the absence of erosion from high velocity water particle that are suspended in wet vapour.
3) *Reducing condenser pressure:*Thermal efficiency of the cycle can be applied improved by reducing the condenser pressure especially in high vacuums. But the increases in efficiency are contained at the increased cost of condensation apparatus.

B. Regenerative Cycle

In the regenerative cycle the dry saturated steam from the boiler enters the turbine at a higher temperature and then expands entropic ally to a lower temperature in the same way as that of Rankin and Carnot cycle. Now the condensate from condenser is pumped back and circulated around the casing, in the direction opposite to the steam flow in turbine. The steam is thus heated before enterin into the boiler. Such a system of heating is known as regenerative heating, as the steam is used to heat the steam itself.

The ideal regenerative cycle has efficiency equal to that efficiency of Carnot cycle with the same heat supply and heat rejection temperature.

$$Q_1 = h_1 - h_4' = T_1 (s1 - s4)$$
$$Q_2 = h_2 - h_3 = T_2 (s2 - s3)$$
$$S4 - s3 = s1 - s2$$
$$S1 - s4 = s2 - s3$$
$$\eta = 1 - \frac{Q2}{Q1} = 1 - \frac{T2}{T1}$$

The efficiency of the ideal regenerative cycle is thus to the Carnot cycle efficiency.

Writing the steady flow energy equation for the turbine

$H_1 - W_t - h_2 + h2 + h4 - h4 = 0$

$W_t = (h1 - h2) - (h4 - h4)$

The pump work remains the same as in the Rankine cycle, i.e.

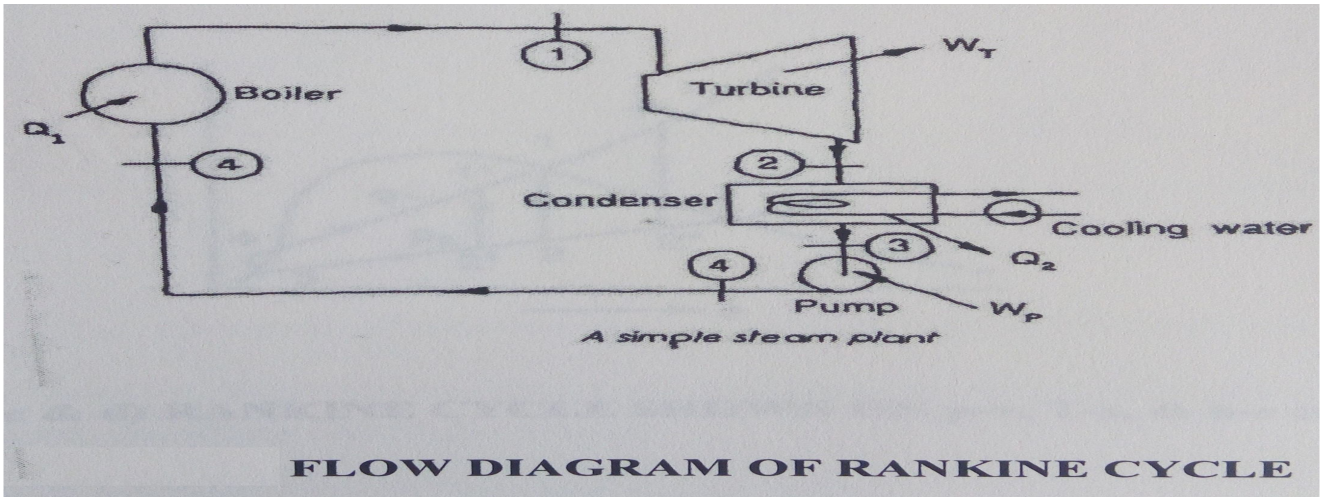
$$W_P = h4 = h3$$

The network output of the ideal regenerative cycle is thus less, and hence its steam rate will be more, although it is more efficient, when compared with the Rankine cycle. However, the cycle is not practicable for the following reason.

Reversible heat transfer cannot be obtained in finite time.

Heat exchanger in the turbine is mechanically impracticable.

The moisture content of the steam in the turbine will be high.

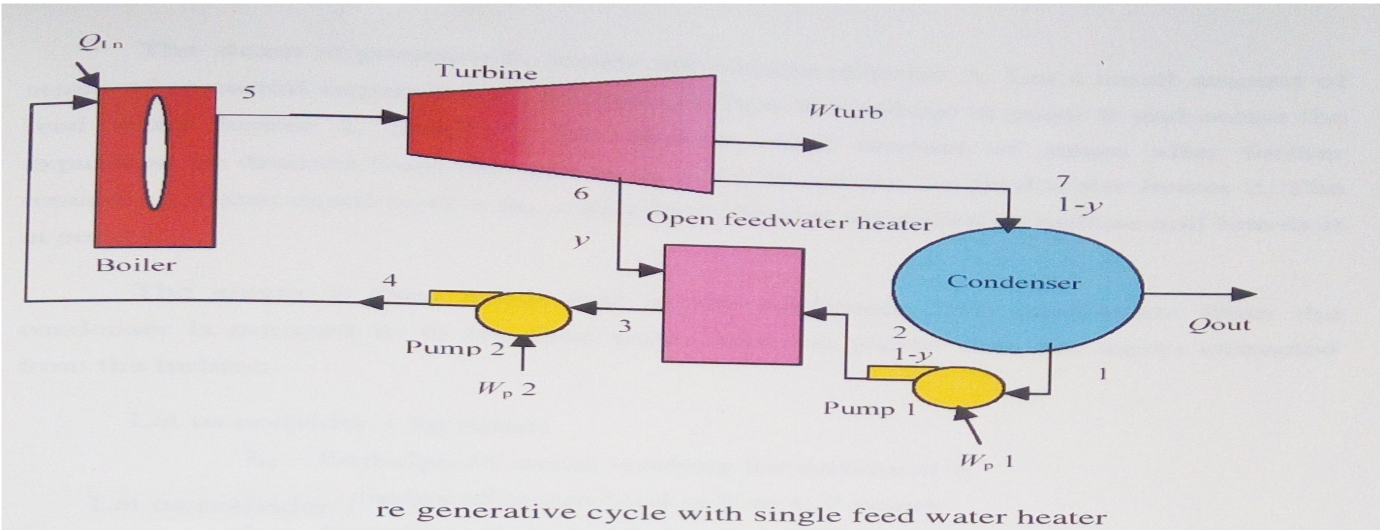


FLOW DIAGRAM OF RANKINE CYCLE

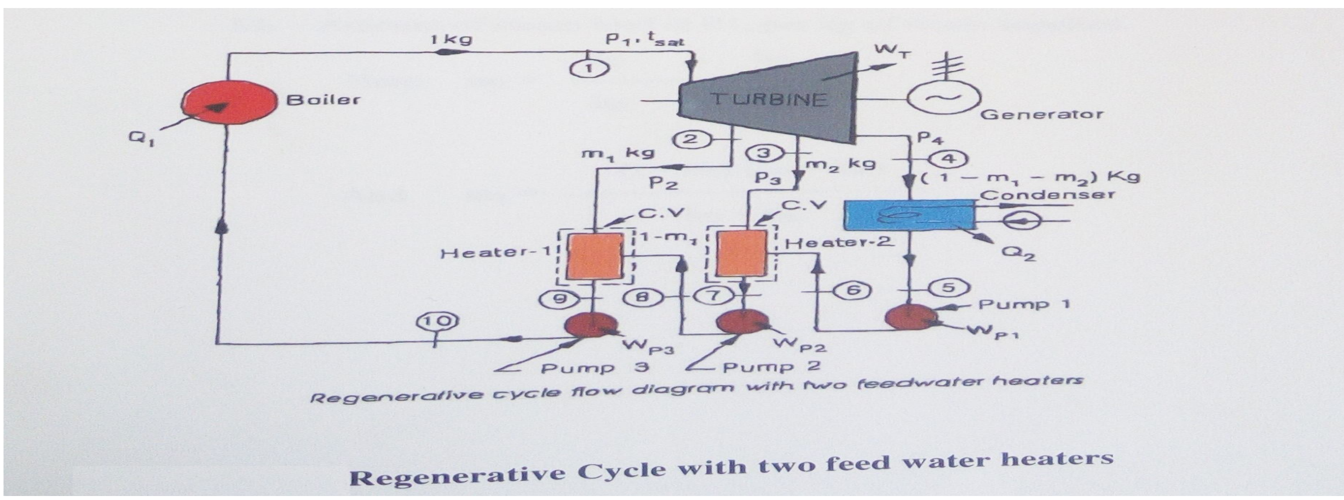
III.REGENERATIVE CYCLE WITH SINGLE FEED WATER

A. Heater

The steam at P I pressure centres the turbine at point A. Let a small amount of wet steam of m kg after partial expansion at pressure P2 be drained from turbine at point B and enters the feed water heater. The remaining steam at presser P3 is further expanded in turbine and leaves at point C.



re generative cycle with single feed water heater



Regenerative Cycle with two feed water heaters

The steam is then condenser in the condenser. The condensate from the condenser is pumped in to the feed water heater, where it mixes up with steam extracted from turbine. The proportion if steam extracted is just sufficient to cause the steam leaving the feed water to be saturated.

$$H_{cycle} = \frac{W_t}{Q_1} = \frac{(h1 - h2) + (I - m)(h2 - h3)}{(h1 - h6)}$$

W_t = Turbine work

Let

h_1 - Enthalpy of steam entering the turbine at A

h_2 - Enthalpy of bled steam

h_3 - Enthalpy of steam leaving the turbine at C

h_{f2} - Sensible heat of feed water leaving the feed water heater

h_{f3} - Enthalpy (or) sensible heat of steam leaving the condenser

h_{f2} - h_{f3}

Where $m = \dfrac{}{h_2 - h_{f3}}$

Efficiency of cycle including the effect of bleeding:

= Total work done / Total heat supplied

$$= \frac{(h_1 - h_2) + (I - m)(h_2 - h_3)}{(h_1 - h_{f2})}$$

The steam at pressure P1 enters the turbine at point A. let a small amount of steam after partial expansion P2 be drained from the turbine at point B and enter the feed water heater 1. Similarly let another small amount of steam after further expansion be drained from the turbine at point B1 enters the feed water heater 2. The remaining steam equal to (1 –M1 – M2) kg is further expanded in turbine and leaves it at point C.

The steam is then condensed in the condenser. The condensate from the condenser is pumped in to the feed water where it mixes with the steam extracted from the turbine.

Let us consider 1 kg steam

h_1 - Enthalpy of steam entering the turbine at A
h_2 - Enthalpy of steam bled at B to L.P heater
h_3 - Enthalpy of steam bled at B1, to H.P heater
h_4 - Enthalpy of steam leaving the turbine at C
h_{f2} - Enthalpy of feed water leaving the feed water heater 1
h_{f3} - Enthalpy of feed water leaving the feed water heater 2
h_{f4} - Enthalpy of steam leaving the condenser
h_{f3} - Enthalpy of feed water leaving the feed water heater 2
h_{f4} - Enthalpy of steam leaving the condenser
M_1 - Amount of steam bled at B per kg of steam supplied
H_2 - Amount of steam bled at B1, per kg of steam supplied.

Here $$m_1 = \frac{h_{f2} - h_{f3}}{h_{f2} - h_{f3}}$$

And $$m_2 = \frac{(1 - M1)(h_{f3} - h_{f4})}{h_{f3} - h_{f4}}$$

A feed water heater as shown in finger 5.a is simply heat exchanger, which preheats the water leaving the condenser and fed to a boiler. The feed heater is supplied by steam which is taken from different stages of turbine. Transfer its latent heat to the boiler feed water and according increases the water temperatures. When the feed heaters are in operation, it requires no resolution because the held steam consumption responds automatically to the temperature and quantity of feed water through the heater.

IV. CONSTURCTION & HEAT TRANSFER IN HP SURFACE FEED HEATER:

The turbine being on the discharge side of the boiler feed pumps these heaters are subjected to a very high pressure and also they use extraction steam which is highly superheated. In addition, unit trip out and charging back heater into service induces cycle stresses of large magnitudes. The heaters are therefore subjected to a very onerous duty.

There are 3 heat transfer zones

The heaters are of vertical coil type with integral de superheating, condensing and drain cooling zones. The feed water flows through the spirals and is heated by steam around the tubes in the shell of the heater. These heaters are cylindrical vessels and shell is made up of boiler quality carbon steel, welded on to a dished end on one side and forge flange on the other side. The longitudinal and circumferential joints are radio graphed as required by IBR. Necessary instruments/accessories such as pressure gauges, and safety relief valves are directly mounted on the shell itself. Level gauges switches and control connection are also mounted on the heater shell. Desecration connections are also provided on the top of the H.P heater shell. Apart from the above, various other connections are provided on the shell as shown in the drawings.

The tube nest consists of a manifold with distributing headers and feed inlet and outlet pipes. This manifold is welded through a dished end. Dished end is welded with a forged flange. Steam inlet pipe is also welded at the center of the dished end at the bottom and will be running up to the top of heater. Tubes bent in the form of spirals are welded to form an integral spiral form of required length. The two ends of the spirals are welded with thicker pieces of stubs. The joints between the two coils and the coil to stub welds are fully radio graphed. The stub ends are welded to distribution pipe. Each spiral tube is separated with steel strips. At an interval of 10-11 or 6-7 spirals, draining diaphragms are provided wherein the condensate collected is drained towards the middle and outlet portions. This will help in reducing the inundation effect over the tubes.

Both feed water and steam entries and exits are from the bottom end of the heater.

Necessary desecrating and drain connections are provided on the tube system. The de superheating and drain cooling zones are completely shrouded with plates for proper distributed of super heater steam in the de superheating zone and hot condensate in the drain cooling zone. The spirals are made of boiler quality carbon steel in the drain cooling zone and condensing zone with alloy steel in the de super heating zone. The tube nest flange and shell flange are welded uniformly with a thin steel strip of thickness 6mm. the shell and tube nest are then bolded down and also the strips are sealed welded to from a high pressure leak proof joint.

For lifting of the heaters, lifting plugs are provided on the shell at a suitable height. At the bottom of the dished end, a skirt of suitable thickness is welded which will serve as a support base for the heater. The skirt has a flange at the bottom on which holes are drilled, for bolting down to the foundation. The heaters are pained on the outside with the ferrate heat resisting aluminium paint before dispatch. The weight of the heater is prominently marked on the heater Operation of H.P heaters

A. Operation

The feed water enters the heater through the feed water inlet pipe and distributes into the two inlet distributing headers fromwhere it passes through spiral coil to the two outlet distributing headers and finally joins the feed water outlet pipe, thus performing the complete path. During its path, the feed water is distributed partly to the under cooling zone and de superheating zone and in full through condensing zone, after which feed water passes through the next higher stage heater and finally to the boiler feed line. The feed water path depends entirely on the heat balance cycle designed from customer. The commonly adapted circuit is as follows.

The feed water from the boiler feed pump enters H.P.H 5 where it is divided, a portion going to the drain cooling zone, the outlet from drain cooling zone joins the other portion and enters the condensing zone.

The outlet from the condensing zone enters H.P.H 6 where it is again divided, a part going to the drain cooling zone, the outlet from which joins the other part and enters the condensing zone, a part of which going the de superheating zone and joins the other part at outlet and enters H.P.H7.

The inlet to H.P.H 7 is divided, a part going to the drain cooling zone, the outlet joining the other part and entering the condensing zone. The outlet from the condensing zone is divided a part going to the de superheating zone and outlet joining the main part. A part of the water enters the de superheating zone of H.P.H 5 and joins the feed water before it enter the economizer. Depending upon the system of feed water path, piping layout is designed.

The super-heated steam for each heater enters through the steam header, provided at the bottom of each heater and flows along the steam pipe line which extends centrally up to the top of the hater . the steam from this pipe flows to the top of one section of the de superheating zone. the steam travels from top to bottom in this section and enters the next section at the bottom through an interconnecting duct. It thus travels in all the four section of the de superheating zone in four passes and finally emerges out from top of last de superheating zone section and enters condensing zone.

In the process the steam losses its super heat to feed flowing in coils and then enter the condensing zone in near saturating condition. While flowing across the coils of the condensing zone, the steam condenses completely and collects at the bottom of the heater. The hot condensate enter one section of the drain cooling zone from the bottom and flows across four sections making four passes, and gives up the heat to the feed water and is finally drained to the next heater of lower stage, or to the desecrator through a set of linter locked valves depending upon the pressure condition inside heater. There is also an arrangement to take out the air steam mixture from each heater which is led to lower high pressure heater /desecrator / condenser.

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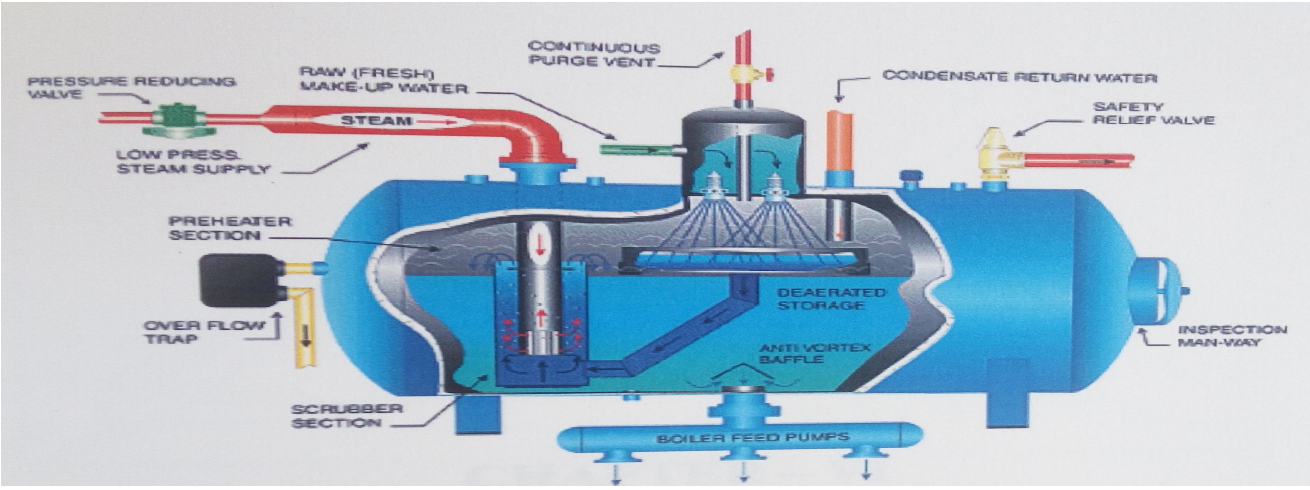
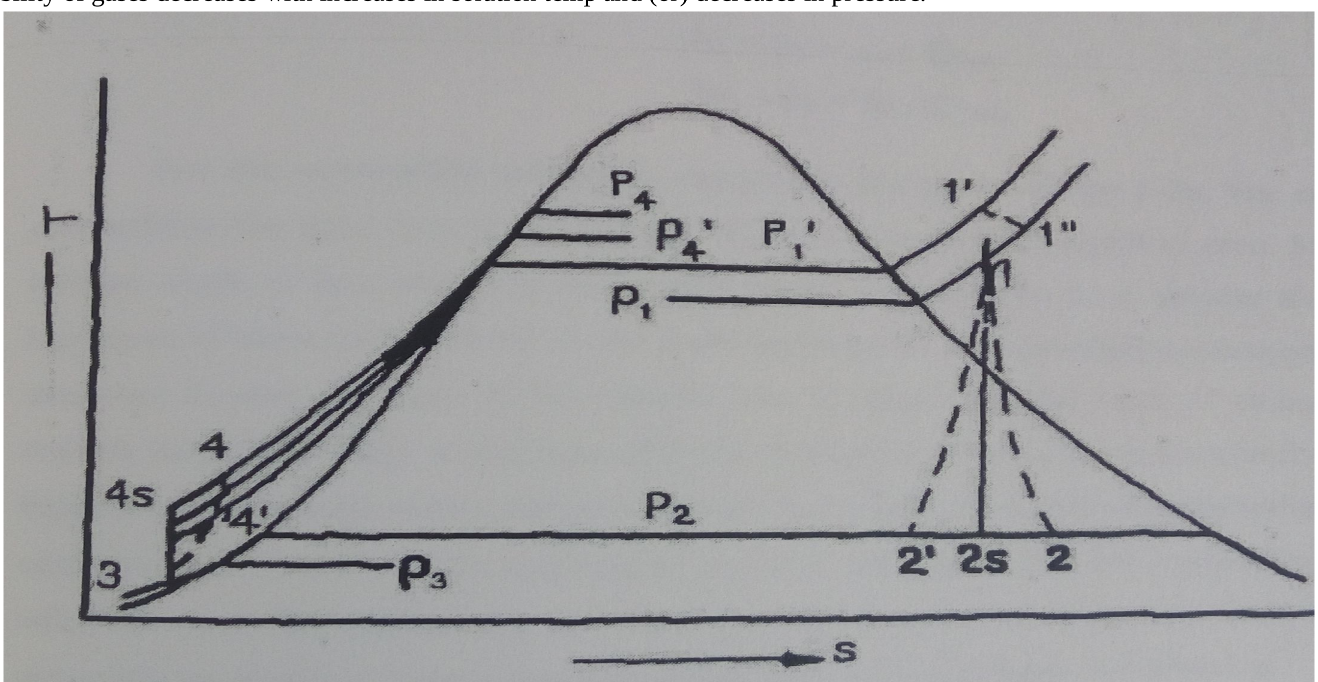


B. Principal

The solubility of any gas dissolved in a liquid is directly proportional to the partial pressure of the gas. This holds with in close limits for any gas which does not react chemically with the solvent.

Solubility of gases decreases with increases in solution temp and (or) decreases in pressure.



Various losses on T-s plot

C. Piping Losses

Pressure drop due to friction and heat loss to the surrounding are the most important piping losses. States 1’ and 1 represent the states of the steam leaving the boiler and entering the turbine respectively, 1’ – 1” represents the frictional losses and 1” – 1 shows the constant pressure heat loss to the surroundings. Both the pressure drop and heat transfer reduce the availability of steam entering the turbine.

A similar loss is the pressure drop in the boiler and also in the pipe line from the pump to the boiler. Due to this pressure drop, the water entering the boiler must be pumped to a much higher pressure than the designed steam pressure leaving the boiler, and this requires additional pump work.

D. Turbine Losses

The losses in the turbine are associated with frictional effects and heats loss to the surroundings. The steady flow energy equation for the turbine in the fig gives.

$$h_1 = h2 + w_t + Q\ loss$$

$$W_t = h1 + h2 - Q\ loss$$

For the reversible adiabatic expansion the path will be 1-2s. For an ordinary real turbine the heat loss is small, and W1 is h1 - h2 with Q2 equal to zero. Since actual turbine work less than the reversible ideal work output, h2 is greater than the h2s. However if there is heat loss to the surroundings h2 will decrease accompanied by the decrease in the entropy. If the heater loss is large the end state of steam from the turbine may 21. It may so happen that the entropy increase due to frictional effects just balance the entropy decrease due to heat loss, with the result that the initial and final entropies of steam in the expansion process are equal, but the expansion is neither adiabatic nor reversible except for very small turbines, heat loss from turbines is generally negligible. The isentropic efficiency of the turbine is defined as

$$H_t = \frac{W_t}{h_t - h_{2s}} = \frac{h_t - h2}{h_t - h2s}$$

Where Wt is the actual turbine work, and – (h1 - h2s) is the isentropic enthalpy drop in the turbine i.e., the ideal output.

E. Pump losses

Where losses in the pump are similar to those of turbine and are primarily due to the irreversibility’s associated with fluid friction. Heat transfer is usually negligible. The pump efficiency is defined as

$$H_p = \frac{h_{4s} - h_3}{W_p} = \frac{h_{4s} - h_3}{h_4 - h_3}$$

Where WP is the actual pump work

F. Characteristics Of An Ideal Working Fluid In Regenerative Power Cycle

There are certain drawbacks with steam as the working substance in cycle. The max temp that can be used in steam cycle consistent with the best available material is about 600Oc, while the critical temp of the steam is 375Oc, which necessitates large superheating and permits the addition of only an infinite amount of heat the higher temperature.

High moisture content is involved in going to higher steam pressure in order to obtain higher mean temp of heat addition (T m). The use of reheat is thus necessitated. Since reheater tube is costly, the use of more than two reheats is hardly recommended. Also as pressure increases the metal stress increases and the thickness of the walls of the boiler drums, tubes, pipe lines etc, increase not only in proportion to increase, but much faster, because of the prevalence of high temperature.

It may be noted that high Tm1 is only desired for cycle efficiency. High pressures are only forced by the characteristic of the steam.

If the lower limit is considered, it is seen that the heat rejection temp of 40OC, the saturation pressure of steam is 0.075 bars, which is considerably lower than the atmospheric pressure. The temp of heat rejection can be still lowered by using some refrigerant as a coolant in the condenser. The corresponding vacuum will be still higher, and maintain such low vacuum in the condenser is a big problem. It is the low temp of heat rejection that is of real interest. The necessity of a vacuum is a disagreeable characteristic of the steam. The saturated vapour line in the T – s diagram of steam is sufficiently inclined, so that when steam is expanded to lower pressure for higher turbine output as well as cycle efficiency. It involves more moisture content, which is not desired from the consideration of the erosion of the turbine blades in later stages.

The desirable characteristics of the working fluid in a regenerative power cycle to obtain best thermal efficiency are given below.

1) The fluid should have a high critical temp so that saturation pressure at the max Permissible temp (metallurgical limit) is relatively low. It should have a large enthalpy of evaporation at that pressure.
2) The saturation pressure at the temp of heat rejection should be above at atmospheric pressure so as to avoid the necessity omaintaining vacuum in the condenser
3) The specific heat of fluid should be small so that little heat transfer is required t to raise the liquid to the boiling point.
4) The saturated vapour line of T – s diagram should be steep, very close to theturbine expansion process so that excessive moisture does not appear during expansion.

5) The freezing point of the fluid should be below room temp, so that it does not et solidified, while flowing through the pipelines.
6) The fluid should be chemically stable and should not contaminate the materials o construction at any temperature.
7) The fluid should be non toxic, non corrosive, not excessively viscous, and low I in cost.Calculations and analysis of different High Pressure Heaters are based on the following data…

G. Technical data

HPH5: vertical coil tpe with integral de superheating and drain cooling zones.

Qty of extraction steam	17661	Kg / hr
Pressure of extraction steam (max)	13	Bar
Enthalpy of extraction steam	3373.89	KJ/kg
Qty. of feed water	660	t/hr
Temp. of feed water at inlet	165	Oc
Temp. of feed water at outlet	186.0	Oc
Size of tubes (D.S. Zone)	32 x 4.0	Mm
No. of spiral coils in De-superheating zone	32	--------------
Surface area : De-superheating zone Condensation zone Drain cooling zone	 84.5 602 84.5	 mm2 mm2 mm2
Design pressure on shell side	14	Atm
Design pressure on water side	265	Atm
Design temp. on shell side	210	Oc
Design temp. on water	210	Oc
Test pressure on shell side	21	Atm
Test Pressure on water side	400	Atm
Over all height	9625	mm

HPH6: vertical coil type with integral de superheating and drain cooling zones.

Qty of extraction steam	47278	Kg / hr
Pressure of extraction steam (max)	27.95	Bar
Enthalpy of extraction steam	3073.54	KJ/kg
Qty. of feed water	660	t/hr
Temp. of feed water at inlet	186	Oc
Temp. of feed water at outlet	222.3	Oc
Size of tubes (D.S. Zone)	OD 32 x 4	Mm
No. of spiral coils in De-superheating zone	32	--------------
Surface area : De-superheating zone Condensating zone Drain cooling zone	 84.5 602 84.5	 mm2 mm2 mm2
Design pressure on shell side	32	Atm
Design pressure on water side	265	Atm
Design temp. on shell side	250	Oc
Design temp. on water	250	Oc
Test pressure on shell side	48	Atm
Test Pressure on water side	400	Atm
Over all height	9625	mm

HPH5: vertical coil type with integral de superheating and drain cooling zones.

Qty of extraction steam	32441	Kg / hr
Pressure of extraction steam (max)	47.97	Bar
Enthalpy of extraction steam	3170.18	KJ/kg
Qty. of feed water	660	t/hr
Temp. of feed water at inlet	222.3	Oc
Temp. of feed water at outlet	245.7	Oc
Size of tubes (D.S. Zone)	32 x 4.0	Mm
No. of spiral coils in De-superheating zone	32	--------------
Surface area : De-superheating zone Condensating zone Drain cooling zone	 84.5 602 84.5	 mm2 mm2 mm2
Design pressure on shell side	32	Atm
Design pressure on water side	265	Atm
Design temp. on shell side	250	Oc
Design temp. on water	250	Oc
Test pressure on shell side	48	Atm
Test Pressure on water side	400	Atm
Over all height	9625	mm

H. Performance analysis of hp heaters.

The performance of feed water heaters can be analyzed by monitoring the Terminal temperature difference (TTD), Drain cooling approach (DCA) and the temp rice across the heater.

To monitoring these it is desirable to carryout simplified routine performance lest on feed water heater at a specified frequency. This will help in identifying the level of deviations & trending of performance.

TTD: The difference between the saturation temp at the heater shell pressure and the temperature of the feed water leaving heater.

DCA: The difference between the temp of the drain leaving the heater & the temp of feed water entering the heater.

TR: The difference between the temp of the feed water leaving the heater & feed water entering the heater.

I. Objective & scope:

1) To provide information to allow evaluation of the working of the feed water heater.

2) Provide information to assist in optimizing the operation of the heater.

J. Calculation & analysis

1) Terminal Temperature Difference:

$$TTD = T_{sat} - T_{(fw\ out)}$$

Where

$T_{(sat)}$ = saturation temp taken at the heater shell pressure, oc

$T_{(fw\ out)}$ = Temperature of feed water leaving the heater, oc

2) Drain cooling approach

DCA = T (drain temp) - T (feed water entering)

T (drains) = temp of the drain leaving the heater, oc

T (fw in) = temp of the drain leaving the heater, oc

3) Temp rise across heater:

T = T (feed water entering) T (feed water leaving)

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K. Designing Data

S.N.	DESICRPTION	UNITS	HEATERS 5	HEATERS 6	HEATERS 7
1	No. Heaters	……….	3		
2	Type	……….	Vertical		
	HP HEATERS		HPH5	HPH6	HPH7
3	Intel FW flow	t/hr	660	660	660
4	FW inlet temp	Oc	165	186	222.3
5	FW outlet temp	Oc	186	222.3	245.7
6	Extern. Steam flow	t / hr	17.661	47.278	32.441
7	Steam (turbine end)	Ata	13	27.95	41.97
8	Steam temp (turbine end)	Oc	453	330	383
9	TTD	Oc	2.0	4.5	2.5
10	DCA	Oc	10	15	7.5
11	TR	Oc	10	15	7.5

S.No.	Description	Units	Run 1	Run 2	Run 3
1	Load	MW	210	211	209
2	MS Pressure	Kg / cm2	128.98	118.8	129.02
3	FW flow	T / hr	660	701.97	684.92
4	HPH5 shell pressure	Kg / cm2	13	11.61	11.32
5	HPH6 shell pressure	Kg / cm2	27.95	25.50	25.8
6	HPH7 shell pressure	Kg / cm2	41.91	39.87	39.04
7	FW temp HPH5 IN	Oc	165	161.95	162.45
8	FW temp HPH5 OUT	Oc	186	179.01	178.78
9	FW temp HPH6 OUT	Oc	222.3	221.58	221.05
10	FW temp HPH7 OUT	Oc	245.7	246.34	245.48
11	Drain temp HPH5	Oc	177	210.29	235.1
12	Drain temp HPH6	Oc	225	210.95	236.01
13	Drain temp HPH7	Oc	248	210.38	235.25

External steam flow = 47278 kg/hr
Steam pressure = 27.95 bar
Steam temperature = 330 oc
Drain temperature = 225 oc

The enthalpy of extraction steam is H steam = 3073.54 KJ/Kg
The enthalpy of drain in H drain = 966.85 KJ/kg
Heat lost by drip coming from HPH 7 = 47278 (3073.54-966.85)
= 99600x103KJ/Hr

Heat lost by drip coming from HPH 7 = 32441(1076.82-966.85)
= 3567.536x103KJ/Hr

Heat gained by feed water = m x cp x (Tsat – T drin)
= 660x103x4.1868x(222.3-1886)
= 100307.35x103 KJ/Hr

Efficiency = heat gained by feed water/
(heat lost by ext steam +heat
Lost by drip from HPH 7)
= 100307.35/(99600+3567.54)
= 97.2 %

V. OBSERVATIONS AND ANALYSIS

From the above calculation it is evident the efficiency of the HP heaters is on higher side kept for HPH-5. The efficiency of the HPH -5 may be lower due to scale formation o0r increased flow velocity due to more number of tube dummies in the tube bundle. However efficiency can be improved by HP jet cleaning chemical cleaning of the tubes and replacement of the tube bundle the cycle efficiency of the plat can be improved.

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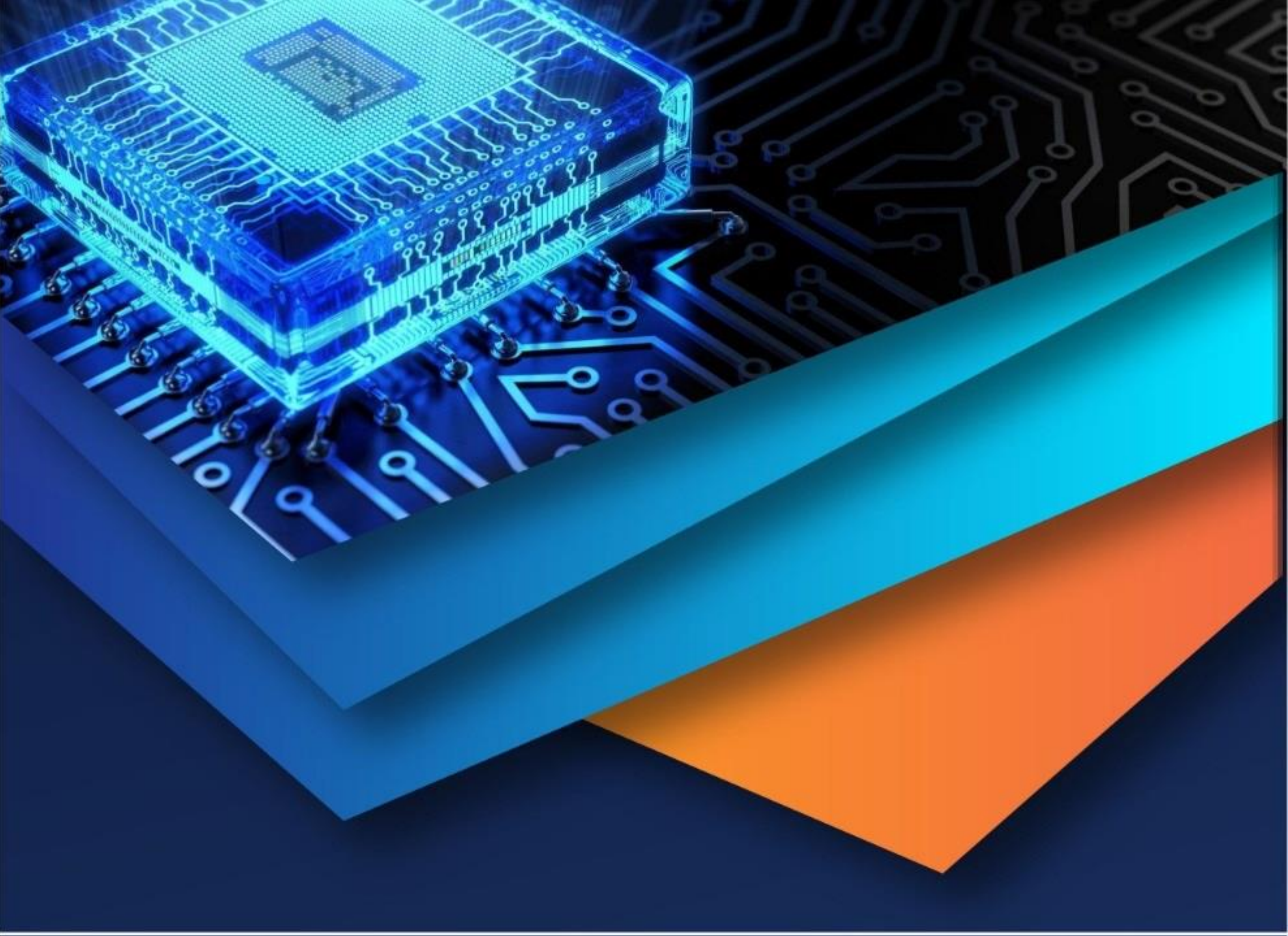

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