

# Derating of 75 MWe Pulverised Coal Fired Power Plant without HP Heaters in Service – A Case Study

**Chittatosh Bhattacharya**

Power Engineering UG & PG Program, National Power Training Institute, Eastern Region, City Centre, Durgapur-713216, India,

**Anuj Pathak**

Power Engineering UG & PG Program, National Power Training Institute, Eastern Region, City Centre, Durgapur-713216, India,

## ABSTRACT

The case study is related to an assessment of derating of power generation capacity of 75 MWe nameplate capacity units due to unavailability of high pressure (HP) heaters of a pulverized coal-fired power generating station in India. The generation capacity of the said Power Plant units, which were commissioned since the 1960s onward, was deteriorated due to trouble in the regenerative feed water heating system. The power generating station was consisting of three 75 MWe BTG units and the generated steam from any of the three similar 320 TPH boilers may be fed to any one of 75 MWe turbo generators through available crossover connections. The study summarizes the results of the series of calculation on collected in-situ data to evaluate the performance and efficiency deterioration due to fall in final feed water (FW) temperature at boiler inlet, as per the provisions of standard thermodynamic 1st law based cycle efficiency evaluation practices. The erosion in IP turbine blades degrades the back pressure on the high-pressure turbine with aging and thereby degrades last HP Heater shell pressure resulting degradation in FW temperature. Bypassing HP heaters affects the same way along increasing condenser losses. Cycle heat rate loss is also inevitable due to emergency drip operation, turbine gland steam leakage, makeup water flow in the condenser. These findings discuss the impact on unit heat rate with reference to design and operating data of 75 MWe generating units while HP Heaters were available and the same were partly or fully unavailable causing performance deterioration.

## Keywords

High pressure feed Water Heaters; Regenerative feed water Heating performance; Power Generation Capacity Derating; Modified Rankine Cycle Efficiency; Power generating plant heat rate evaluation.

## 1. INTRODUCTION AND BACKGROUND

Rankine steam cycle, adapted in pulverized coal-fired thermal power generation with due modifications accommodating regenerative feed water (FW) heating and superheating along reheating has shown that increased efficiency requires increased Boiler pressure, the degree of superheat (SH) and degree of reheat (RH) to improve steam heat content and to minimize condenser heat rejection.

These improvements almost reached the peak of the boiler strength, high-temperature metallurgy and cooling system efficiency for the condenser. The ideal Rankine steam cycle performance improvement in subcritical regime is relatively insignificant even with the moderate increase in the upper temperature limit compared to supercritical or advanced ultra-supercritical regime of operation.

As such, the Regenerative FW Heating system has progressed cycle efficiency more. Modified cycle is certainly more efficient where heat added to FW by the steam bled from the turbine at points intermediate between throttle and exhaust reduces heat rejection in the condenser. Heat rejected in circulating cooling water system of the condenser is the major loss in the turbine cycle. Heat regenerated through closed or open condensing heaters after partial expansion of steam, is used for sensible heating of the condensate/FW at lower pressure heaters (LPH) or high-pressure heaters (HPH) before cascaded to condenser, results in more heat including latent heat in the steam to remain within the cycle, reducing heat rejection in the condenser and cycle efficiency increases up to 4%. However, specific work output (Power output per kg of steam) of cycle decreases due to steam extractions, reducing turbine output. In this type of FW heating boiler efficiency may also decrease, due to high stack loss as a result of high Economizer FW inlet temperature thereby, increasing flue gas exit temperature of the boiler. Therefore, maximum 30-32% steam may be extracted from the turbine for regenerative FW heating purpose. Therefore, optimization of FW temperature close to design condition at boiler inlet is crucial in balancing the heat absorption in boiler water-steam circuit along optimization of exhaust dry flue gas loss.

The Power Plant units under consideration in the present discussion were commissioned since the 1960s onward, but in recent past, the generation was deteriorated due to trouble in the regenerative feed water heating system. The power generating station was consisting of three 75 MWe gross power generating units and the generated steam from any of the three similar 320 TPH boilers may be fed to any one of 75 MWe turbo generators through available crossover connections.

Basic Feature in 75MWe generating units Regenerative feed water heating system: Two types of feed heaters are provided in condensate and FW heating cycle. The heaters, which are placed in FW cycle i.e. after boiler feed pump (BFP) discharge and where water pressure is high, are called high-pressure heaters (HPH). The extraction pressure and temperature for these heaters

## Derating of 75 MWe PC Fired Power Plant without HP Heaters in Service – A Case Study

are also high. Two numbers of HP heaters are provided in 75 MWe units namely HPH-1 and HPH-2. On the other hand, the heaters, which are placed in condensate line and where water pressure, as well as steam pressure and temperature, are less is called low-pressure heaters (LPH). Three numbers of LP heaters are provided in each 75 MWe units namely Deaerator Heater, LPH, and Vacuum Heater (VH).

There are five extractions from the 75 MWe unit turbines providing uncontrolled steam flow to 2 nos. inverted U type HP heaters, 2 inverted U type LP heaters and one extraction to deaerator that is of direct condensing type. The regenerative FW heating cycle starts at condenser at a significantly low pressure and ends at economizer inlet at a high pressure. The typical layout of the regenerative FW heating in T-s diagram for 75 MWe plant is shown in Fig.-1. For regulating FW heating of condensate five extraction points are provided from various stages of the turbine as follows:-

One extraction connection is from HP turbine exhaust line termed as Extraction No. 5 (to HPH -1), three extraction connections are from IP turbine termed as Extraction No. 4 (to HPH-2), Extraction No.3(to Boiler Feed Tank) and Extraction No.2 (from IP to LP crossover pipe to LP heater) respectively. The lowest pressure extraction (extraction no. 1) from LP heater is supplied to Vacuum Heater (LP Heater no 1)

HPH-1 extraction is taken from HP turbine outlet line. This line consists of one non-return valve and one gate valve. The non-return valve closes under turbine trip condition and it also closes on heater level reaching very high set value to safeguard turbine from water ingress. Isolating valve also closes due to above said reason primarily to safeguard turbine from water ingress in the case of tube rupture in feed water heater. A drain line is provided in this extraction with an isolating valve.

HPH- 2 extraction steam line is provided with pneumatically operated non- return valve and gate valve. NRV closes under turbine trip condition primarily to prevent over speeding of turbine and it also closes on heater level high set value to prevent water ingress into the turbine. A drain line is provided in this extraction with isolating valve.

Extraction No. 3 is taken from IP turbine and this extraction steam is used for deaerator pegging/ Boiler feed tank heating. Extraction line is provided with one non-return valve (NRV) and one isolating valve. Extraction No. 2 is taken from cross-around pipe (CAP) inlet to LP turbine and is connected to LP heater no. 2 (commonly referred as LPH). This line is provided with electrically / pneumatically assisted NRV and a gate valve. The important permissive for extraction valve opening and check valve tripping (if any of the following permissive is withdrawn) are a) LPH drip level not very high; b) Secondary valve control oil pressure is not low; c) Turbine is not tripped. Two drains are provided in this extraction line with motorized valves. Extraction No.1 is taken from LP cylinder 7th stage. This extraction line is provided with an isolating valve. No NRV is provided in this line.

**Heater Vent System:** The presence of air in heaters deteriorates its performance. To remove this air, all the heaters are provided with a vent connection on the heater shell. LP heaters and HP heater vents are individually taken to condenser and deaerator respectively through vent lines, which are provided with an orifice and a regulating valve (connected in series) to restrict vent flow. Additionally, HP heaters are provided with vents for startup purpose, which are led to the atmosphere. The deaerator

vents discharge to the atmosphere. The vent line has been provided with a globe valve and orifice. Additionally, deaerator is provided with motorized globe valve for start-up.

**Heater Drain System:** During normal operation, all the heater drips are cascaded from high-pressure heater to next lower pressure heater. HPH-1 drip is cascaded to HPH-2 through a non-return valve and then drip from HPH-2 is cascaded to Deaerator through control valve at normal operation. HPH-1 drip is also individually cascaded to Deaerator. Similarly, the drip from LPH is cascaded to Vacuum Heater (VH) and finally drip from VH is taken to the condenser through Drain Cooler and LP drain the flash tank. In the case of high level of any heater, drip from that heater is taken directly to the condenser through drain flash tank. HPH-1 & HPH-2 high-level drips are fed to condenser respectively via HP drain Flash Tank. Similarly, LPH & Vacuum Heater high-level drips are fed to condenser via LP drain Flash Tank. In the case of an outage of any heater, drip from the preceding higher pressure heater is also taken directly to the condenser through the drain flash tank, except HP heater-1 drain, which is led to Deaerator when HP heater-2 is not available.

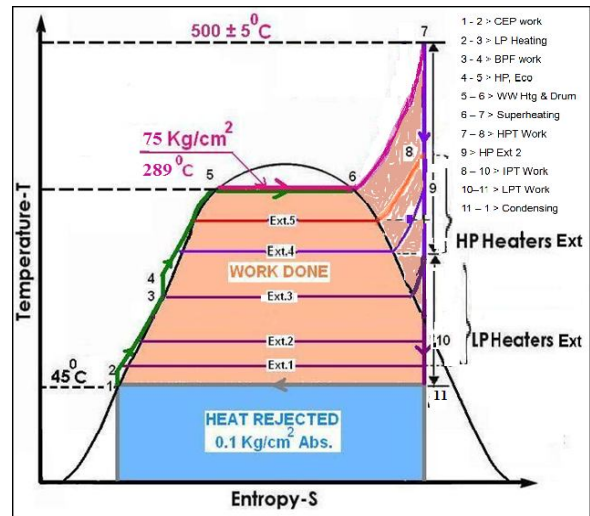


Figure 1: Turbine Extraction Layout T-S diagram

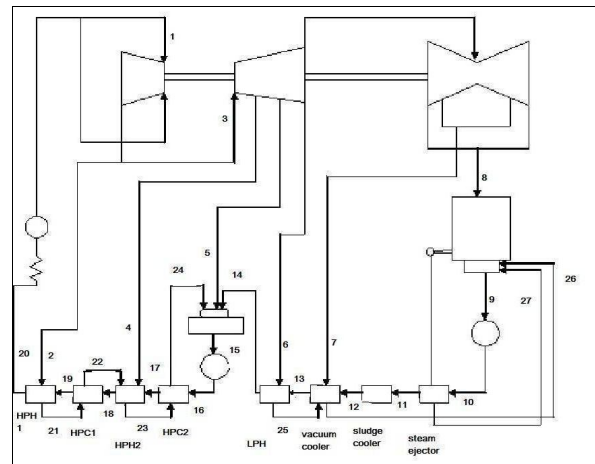


Figure 2 : Schematic layout of heaters & Extraction

## 2. FACTORS AFFECTING HEATER PERFORMANCE

A FW heater is a component designed to heat a given quantity of FW through a specified temperature range with steam at a specified enthalpy and pressure and with a limited pressure loss of the FW passing through the unit. The usual arrangement of this type of heater is a shell and tube unit with FW passing through the tubes which are surrounded by the heating medium (steam). The heating surface within the unit may be subdivided into zones as outlined below: -Condensing zone; De-superheating zone and Drain cooling or sub-cooling zone.

The performance of FW heaters can be analyzed by monitoring the terminal temperature difference (TTD), drain cooler approach (DCA) temperature, the pressure drop of FW side and the temperature rise across the heater. TTD or Terminal temperature difference is the difference between the saturation temperature corresponding to the extraction steam inlet pressure and the FW outlet temperature. The DCA or Drain cooler approach is the difference between the drain outlet temperature and FW inlet temperature. The major causes of FW heater performance deviations are linked to scale deposition on heater tubes; leakage of heater tubes; Reduced FW flow through the heater; failure to vent the non-condensable gases or air-blanking; or changes in heater condensate level.

Scale deposition on the FW heater tubes may be caused by leaks in the condensate flowing tubes. The primary effect of tube fouling can be seen as an increase in the FW heater tube bundle pressure drop, an increase in the heater TTD and decrease in the gain of FW temperature in the heater. Tube leakage of FW heater can have a number of effects on the efficient operation of FW heater. If the tube leaks are in the shell area outside of the drain cooling zone, FW flow will be diverted. If this amount of diversion flow is significant, the demand upon the BFP/CEP will be increased which in turn requires high auxiliary power consumption. If the FW diversion into the shell side is large enough, the emergency drain valve (high drip level controller) will open to maintain the heater shell side level which results in high-temperature hot fluid will be returned to the condenser. As a result of this condenser duty will increase and flow requirements of CEPs will be increased.

Increased demand upon the normal cascading drain and the emergency drain can reduce the pressure in the drain cooling zone causing flashing and increase in the DCA temperature difference as well as possible damage to the FW heaters. FW heater water box partition plate passing causes short circuiting and therefore required a rise in temperature of FW is not achieved which results in increased TTD. High Heater level caused by the tube leakage may cause the damage of turbine blade due to the ingress of water particles into the turbine through extraction steam line.

Reduced FW flow through the heater can cause the starvation of heater tubes which results in tube leakage of the heater. If non-condensable gases are not vented properly from the heater, the FW temperature gain will be decreased and TTD will be increased. FW heater level is another parameter which is critical to plant performance. FW heater level should be maintained to prevent flashing from occurring in the drain cooler sections and to avoid the possibility of heater tube damage. Since leaking FW tubes are normally plugged with no adjustment made to heater

shell side level, the problem is normally compounded. Excessive tube plugging in the shell area will begin to reduce the heat transfer area of the heater and have a significant effect on its operation. If the tube plugs are in the drain cooler section, the effect will be for flashing to occur in this section with the resultant increase in the DCA and possibly additional damage to the heater.

Erosion caused by the solid particles in HP and IP turbines result in higher nozzle area causing a degraded inlet pressure to HP/IP turbine and a reduced specific volume caused by lower steam temperature. Then again, erosion in IP turbine blades degrades the back pressure on HP turbine and thereby degrades last HP heater shell pressure. This in turn leads to degrading final FW temperature since TTD trend constant only at full load operation. In fact, 1°C increase in TTD due to poor heater performance for tube scaling or any other failure results in 0.027% loss of cycle efficiency. When HP heaters are kept out of service for various reasons, it affects the final FW temperature to the boiler.

The schematic layout of 75 MWe PC-fired power generating unit regenerative FW heating plan is shown in fig.-2. The generated steam from radiant, natural circulation, single drum, balanced draft, dry bottom, front fired (tilting-tangential: for one unit and front fired for other two units), auxiliary fuel oil and primary coal fired with the direct ignition PC firing system boiler, is entering and expanding in HP turbine. The part of HP turbine exhaust steam bled to use in HP heater (HPH-1) for regenerative FW heating which is an uncontrolled extraction to meet final feed heating demand.

The major amounts of HP turbine exhaust admitted to IP turbine. HPH-1 is heated with extracted steam of IP turbine. The extracted steam is also used for heating in boiler FW tank (BFT) attached to deaerator which is only direct contact open heating arrangement. The part of IP turbine exhaust is used for heating the condensate in LP heaters (LPH). The major part of IP turbine exhaust is further expanded in low-pressure (LP) turbine before discharging in condenser hot well. VH is heated with extracted steam from 7th stage LP turbine blading. Again condensate of LPH is cascaded to Vacuum Heater (VH). The condensate from VH is fed back into the FW in the regenerative feed heating system after cascading to flash boxes of gland steam condenser and drain coolers.

Condensate FW pumped by the condensate extraction pump (CEP) after passing through VH and LPH is fed into the deaerator attached to BFT from where suction is taken for boiler feed pump (BFP). The BFP discharge is passed through HPH-2 and HPH-1 successively before moving to FW regulating station for control FW flow in the boiler. The condensate of HPH-1 is cascaded to the main condensate in HPH-2 which is subsequently fed into BFT. The detail of heat balance per unit working fluid flow is as given below to find out the maximum operating efficiency of the aforesaid system as shown in table - I in Annexure for bled steam quantity m1, m2, m3, etc evaluated in kg/kg of main steam flow in the turbine.

### 3. HEAT BALANCE CALCULATIONS WITH ALL HP HEATERS IN SERVICE

[Operating parametric values adopted from Performance Guarantee (PG) test Report conducted post RLA/LEP of units Ref. Fig. – 2]

Heat and mass balance at HPH-1:-  $m_1 (h_2-h_{21}) = (1-m_1) (h_{20}-h_{19}) \gg m_1 = 0.0495 \text{ kg/kg steam}$ . Heat and mass balance at HPH-2:  $m_2(h_4-h_{23}) + m_1(h_{22}-h_{23})=(1-m_1-m_2)(h_{18}-h_{17}) \gg m_2 = 0.0375 \text{ kg/kg steam}$ ; Heat and mass balance at BFT heating:  $m_3 (h_5-h_{15}) + (m_1+m_2) (h_{24}-h_{15}) = (1-m_1-m_2-m_3) (h_{15}-h_{14}) \gg m_3= 0.0251 \text{ kg/kg steam}$ . Heat and mass balance at LPH:-  $m_4 (h_6-h_{25}) = (1-m_1-m_2-m_3-m_4)(h_{14}-h_{13}) \gg m_4 = 0.0454 \text{ kg/kg steam}$ . Heat and mass balance at VH –  $m_5 (h_7-h_{26}) + m_4 (h_{25}-h_{26}) = (1-m_1-m_2-m_3-m_4-m_5) (h_{13}-h_{12}) \gg m_5=0.0301 \text{ kg/kg steam}$ . Work done by Turbine,  $WT= (h_1-h_3) + (1-m_1)(h_3-h_4) + (1-m_1-m_2)(h_4-h_5) + (1-m_1-m_2-m_3)(h_5-h_6) + (1-m_1-m_2-m_3-m_4)(h_6-h_7) + (1-m_1-m_2-m_3-m_4-m_5)(h_7-h_8) = 748.33 \text{ KJ/Kg}$ ;

Pump Work (for CEP + BFP),  $WP = (1-m_1-m_2-m_3) v_9 (P_{10}-P_9) + v_{15} (P_{16}-P_{15}) = 12.2 \text{ KJ/Kg}$ ; Net Work output,  $W=WT-W_p = 736.18 \text{ KJ/Kg}$  ; Heat Addition:  $Q = (h_1-h_{20}) = 2505.53 \text{ KJ/Kg}$ ; Efficiency:-  $\eta=W/Q= 0.2938=29.38\%$  ; Heat Rate,  $HR = 3600 / \eta = 12253.2 \text{ KJ/KWh}$ .

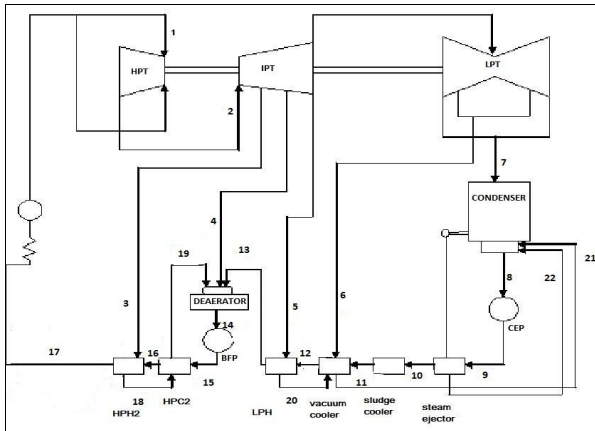


Figure 3: Scheme of heaters & extraction except HPH - 1

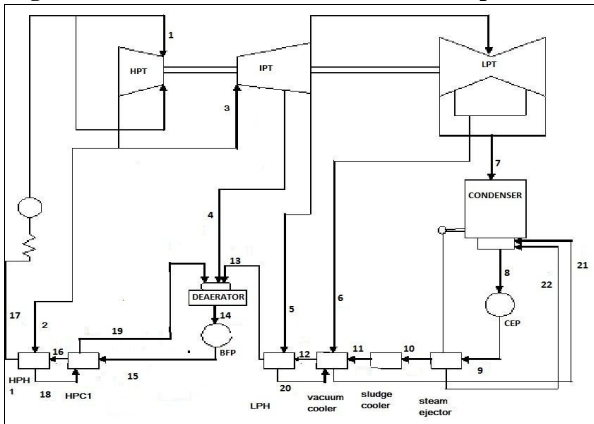


Figure 4: Scheme of heaters & extraction except HPH - 2

### 4. CALCULATIONS OF SYSTEM EFFICIENCY AT VARIOUS OTHER CONDITIONS

The same parametric analysis was carried at other conditions, i.e., only HPH-1 out of service, only HPH-2 out of service and both HPH-1 and HPH-2 out of service. The thermodynamics parameters at various stages of working fluid at all conditions are given in Table II, Table III, Table IV & Table V respectively in Annexure. In certain condition, due to unavailability of measurable parameters of pressure or temperature value, assumptions are made matching the parametric condition of extraction steam flow at various loading point as recorded during physical plant data collection along PG test report values and TERI energy Audit Report of same plant.

#### 4.1 Calculations with only HPH-1 out of service

(\*Assuming same mass flows through all extractions steam lines irrespective of heater by-pass arrangement and without any pressure deviation Ref. Fig.3):

Heat and mass balance at VH:  $m_4 (h_6-h_{21}) + m_3(h_{20}-h_{21}) = (1-m_1-m_2)(h_{12}-h_{11}) \gg h_{12}= 430.84 \text{ KJ/kg}$  ; Therefore, FW temp at VH outlet  $102.5^\circ\text{C}$ . Heat and mass balance at LPH:  $m_3(h_5-h_{20}) = (1-m_1-m_2)(h_{13}-h_{12}) \gg h_{13} = 545.66 \text{ KJ/Kg}$ ; Therefore, FW temperature at LPH outlet  $129.6^\circ\text{C}$ . Heat and mass balance at BFT heating (considering BFP inlet temp of FW  $150^\circ\text{C}$ , available head – 5.6 bar):-  $m_2(h_4-h_{14})+m_1(h_{19}-h_{14}) = (1-m_1-m_2)(h_{14}-h_{13}) \gg h_{19}=1279.41 \text{ KJ/Kg}$ ; Therefore, HPC2 drip temperature at BFT inlet is  $185.2^\circ\text{C}$ . Heat and mass balance considering BFT, HPC2 & HPH-2 as Single Heater:  $m_2(h_4)+m_1(h_3)+(1-m_1-m_2)h_{13} = h_{17} \gg h_{17}= 697.91 \text{ KJ/Kg}$ ; Therefore, Final FW temperature to Economizer is  $163.9^\circ\text{C}$ .

Heat and mass balance considering HPC2 and HPH-2 as Single Heater:  $m_1(h_3) + h_{15} = h_{17} + m_1(h_{19}) \gg h_{15} = 632.23 \text{ KJ/Kg}$  ; Turbine work output,  $WT = (h_1-h_3) + (1-m_1) * (h_3-h_4) + (1-m_1-m_2)(h_4-h_5) + (1-m_1-m_2-m_3) (h_5-h_6) + (1-m_1-m_2-m_3-m_4)(h_6-h_7) = 774.99 \text{ KJ/Kg}$  ; Pump Work,  $W_p:- (1-m_1-m_2)v_8(p_9-p_8) + v_{14}(p_{15}-p_{14}) = 12.33 \text{ kJ/kg}$ ; Net Work,  $W=WT-W_p = 762.66\text{KJ/Kg}$  Heat Addition,  $Q= (h_1-h_{17}) = 2713.12 \text{ KJ/Kg}$ ; Efficiency,  $\eta=W/Q= 0.2811=28.11\%$  Heat Rate,  $HR=3600/\eta=12806.8 \text{ KJ/KWh}$

#### 4.2 Calculations with only HPH-2 out of service

(\*Assuming same mass flows through all extractions steam lines irrespective of heater by-pass arrangement and without any pressure deviation Ref. Fig.4):

Heat and mass balance at Vacuum Heater:  $m_4 (h_6-h_{21}) + m_3 (h_{20}-h_{21}) = (1-m_1-m_2)(h_{12}-h_{11})$  ;  $\gg h_{12} = 431.89 \text{ KJ/Kg}$ ; Therefore, FW temp at VH outlet  $102.8^\circ\text{C}$ . Heat and mass balance at LPH:-  $m_3(h_5-h_{20}) = (1-m_1-m_2) (h_{13}-h_{12}) \gg h_{13}= 548.2 \text{ KJ/Kg}$ ; Therefore, FW temp at LPH outlet  $130.2^\circ\text{C}$ . Heat and mass balance at BFT heating :-  $m_2(h_4-h_{14}) + m_1(h_{19}-h_{14}) = (1-m_1-m_2)(h_{14}-h_{13}) \gg h_{19}= 1054.03 \text{ KJ/Kg}$ ; Thus, HPC1 drip temp at BFT inlet  $206.2^\circ\text{C}$ . Heat and mass balance considering BFT, HPC2 & HPH-2 as single heater:-  $m_1 (h_2)+m_2(h_4)+(1-m_1-m_2) h_{13} = h_{17} \gg h_{17} = 735.45 \text{ KJ/Kg}$ ; Therefore, Final FW temperature to Economiser  $172.6^\circ\text{C}$ . Heat and mass balance

considering HPC2 & HPH-2 as single heater:  $- m_1(h_2)+h_{15}=h_{17}+m_1(h_{19}) \gg h_{15}= 632.23 \text{ KJ/Kg}$ .

Turbine work output, WT:-  $(h_1-h_3)+(1-m_1) \cdot (h_3-h_4)+(1-m_1-m_2)(h_4-h_5)+(1-m_1-m_2-m_3) \cdot (h_5-h_6)+(1-m_1-m_2-m_3-m_4)(h_6-h_7)=764.46 \text{ KJ/Kg}$  ; Pump Work, Wp:-  $(1-m_1-m_2)v_8(p_9-p_8) + v_{14}(p_{15}-p_{14}) =12.31 \text{ kJ/kg}$ ; Net Work,  $W=WT-W_p = 752.15\text{KJ/Kg}$ ; Heat Addition,  $Q= (h_1-h_{17}) = 2655.9 \text{ kJ/kg}$ . Efficiency,  $\eta=W/Q= 0.2812=28.12\%$ ; Heat Rate,  $HR =3600/\eta=12802.8 \text{ KJ/KWh}$

**Table – 1: Requirement of Extraction Steam flow for HP Heaters on PG Test Values in t/h**

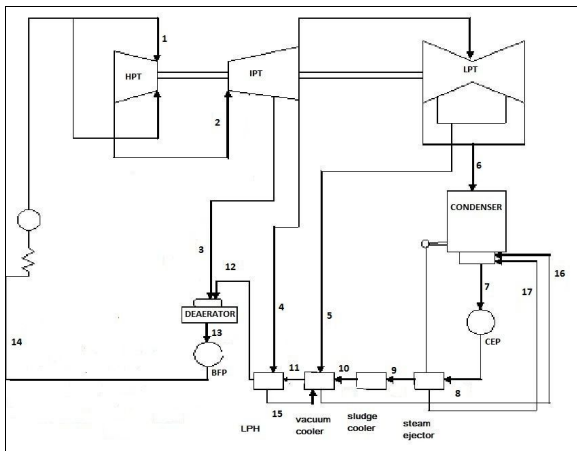
Parameter	Unit # B	Unit # A	Unit # C
Main Steam	307.6	314.2	317.19
HPH-1	12.19	17.216	17.573
HPH-2	14.145	17.216	17.573
Main Condensate	266.268	267.586	266.7

### 4.3 Calculations for both HPH-1 and HPH-2 out of service

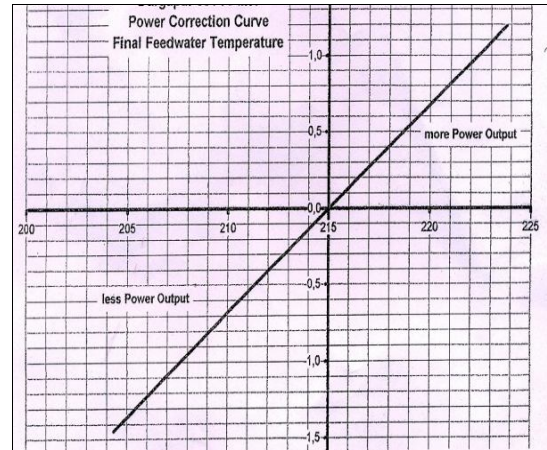
(\*Assuming same mass flows through all extractions steam lines irrespective of heater by-pass arrangement and without any pressure deviation Ref. Fig.5) at Unit - A:

Heat and mass balance at VH:  $- m_3 (h_5-h_{16})+m_2(h_{15}-h_{16}) = (1-m_1)(h_{11}-h_{10})$   $h_{11} = 258.5 \text{ KJ/Kg}$  ; Therefore, FW temp at VH outlet  $61.5^\circ\text{C}$ . Heat and mass balance at LPH:  $- m_2 (h_4-h_{15}) = (1-m_1)(h_{12}-h_{11}) \gg h_{12} = 367.91 \text{ KJ/Kg}$ ; Therefore, FW temp at LPH outlet  $87.6^\circ\text{C}$ . Heat and mass balance at BFT heating:  $- m_1 (h_3-h_{13})=(1-m_1)(h_{13}-h_{12}) \gg h_{13} = 431.35 \text{ KJ/Kg}$ ; Therefore, Final FW temperature to Economiser  $150.02^\circ\text{C}$ .

Turbine work,  $WT = (h_1-h_3)+(1-m_1)(h_3-h_4)+(1-m_1-m_2)(h_4-h_5)+(1-m_1-m_2-m_3)(h_5-h_6) =786.16 \text{ KJ/Kg}$  ; Pump Work,  $W_p = \{(p_{14}-p_{13})v_{13}+(p_8-p_7)v_7(1-m_1)\} \cdot 10000\text{J/s}$  as p is in  $\text{kg/cm}^2 = 6.87 \text{ KJ/Kg}$  ; Net Work ,  $W=WT-W_p =779.29\text{KJ/Kg}$  Heat Addition,  $Q = (h_1-h_{14})+(h_{14}-h_{13}) = 2799.52\text{KJ/Kg}$ ; Efficiency,  $\eta=W/Q= 0.2784=27.84\%$ ; Heat Rate,  $HR=3600/\eta=12932.63\text{KJ/KWh}$



**Figure 5: Scheme of various heaters & extraction except HPH1 and HPH -2**



**Figure 6: Correction curve for change in final FW temperature (Rated final FW temp  $215^\circ\text{C}$  at 77MWe.)**

### 4.4 Calculations for both HPH-1 and HPH-2 out of service

(\*Assuming same mass flows through all extractions steam lines irrespective of heater by-pass arrangement and without any pressure deviation Ref. Fig.5) at Unit - B:

Heat and mass balance at Boiler Feed Tank (BFT) Heating:  $- m_1 (h_3 - h_{13}) = (1 - m_1) (h_{13} - h_{12}) \gg m_1 = 0.0353 \text{ kg/s}$  ; Heat and mass balance at LPH:  $- m_2 (h_4 - h_{15}) = (1 - m_1 - m_2)(h_{12} - h_{11}) \gg m_2 = 0.0732 \text{ kg/s}$ ; Heat and mass balance at VH:  $- m_3(h_5-h_{16})+m_2(h_{15}-h_{16})=(1-m_1-m_2-m_3)(h_{11}-h_{10}) \gg m_3=0.00968\text{kg/s}$  ;  $h_1= 3403.63\text{kJ/kg}$ ;  $h_6 = 3403.63\text{kJ/kg}$

After condenser, the CEP pumps the liquid, so at point 7,  $v_6 = 0.00101\text{m}^3/\text{kg}$ ;  $p_{13}$  at BFP inlet=  $5.03957 \text{ kg/cm}^2$ ;  $p_{14} = 113.21\text{kg/cm}^2$ ,  $v_{13} = 0.00107427 \text{ m}^3/\text{kg}$ ,  $p_8 =16.25\text{kg/cm}^2$ ; TurbineWork,  $WT=(h_1-h_3)+(1-m_1)(h_3-h_4)+(1-m_1-m_2)(h_4-h_5)+(1-m_1-m_2-m_3)(h_5-h_6)=781.62 \text{ kJ/s}$ ; Pump Work:  $WP=\{(p_{14}-p_{13})v_{13}+(p_8-p_7)v_7(1-m_1-m_2-m_3)\} \cdot 10000\text{J/s} =1.306\text{kJ/s}$ ; Net Work:  $WN=WT-WP =779.29 \text{ kJ/s}$  ; Heat Addition:  $Q = (h_1-h_{14}) + (h_{14}-h_{13}) =2837.51\text{kJ/s}$  ; Efficiency:  $=WN/Q=27.50\%$  ; Heat rate:  $HR=3600/\eta = 13090.90 \text{ kJ/KW}$

Assumptions: 1) The deaerator is at a height of 20 m above BFP inlet. 2) The pressure drop across each heater after CEP to BFP is  $0.3\text{kg/cm}^2$ ; for a heat rate of 12282.5, the gross generation was 75 MWe; for heat rate of 13090.90, the gross generation was 70.37 MWe

## 5. IMPACT OF HP HEATERS IN SYSTEM EFFICIENCY AT DIFFERENT CONDITIONS

From the above analysis of performance guarantee test data and the operating parameters at various conditions of the units, evidently, there is a substantial loss of efficiency due to improper regenerative FW heating. It is true that despite close control over steam flow, FW flow and fuel flow, continuous fluctuation in load demand and turbine blade erosion or deposition cause considerable variation in Boiler FW inlet temperature. Regulating the final FW temperature close to design specification enhances

## Derating of 75 MWe PC Fired Power Plant without HP Heaters in Service – A Case Study

and maintains system efficiency. Typically 3.5°C degradation in final FW temperature is worth heat rate penalty of 89.68 kJ/kWh.

With reference to above discussions, in 100% Maximum Continuous Rating condition, the FW inlet temperature to economizer with both the HP heaters in service is 210.9°C. It is seen that in same MCR operation, without HPH-1 only and without HPH-2 only, the FW inlet temperature to boiler reduces to 163.9°C and 172.6°C respectively. Whereas with both the heaters kept out of service, the final FW inlet temperature to Boiler reduces to 150.02°C to 136.38°C in two different units respectively. This drop in FW temperature is equivalent to a heat rate penalty of 340.52 KJ/kWh, 573.42 KJ/kWh, 650.43 KJ/kWh respectively in each case.

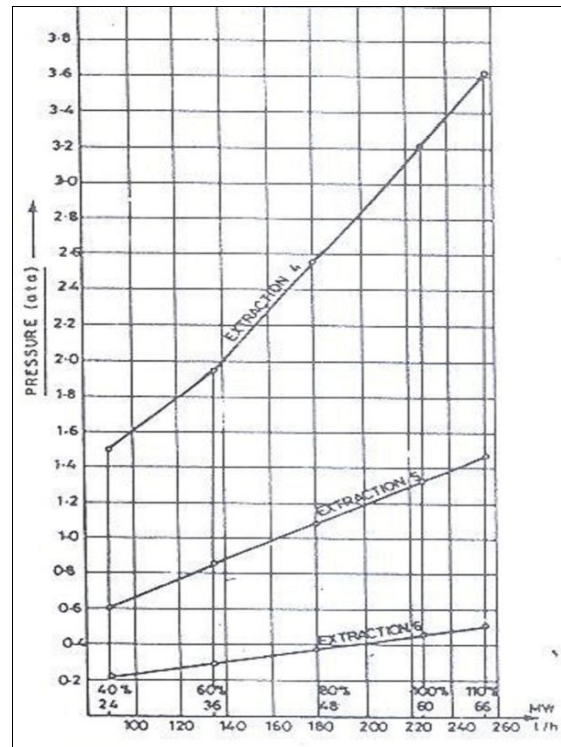
The above discussion shows the capacity of said power plant units of 75 MWe at different conditions. The comparison of all the conditions with respect to efficiency, HR, and some other parameters are shown below in the Table - 2.

**Table – 2: HP Heater(s) effect on system parameters**

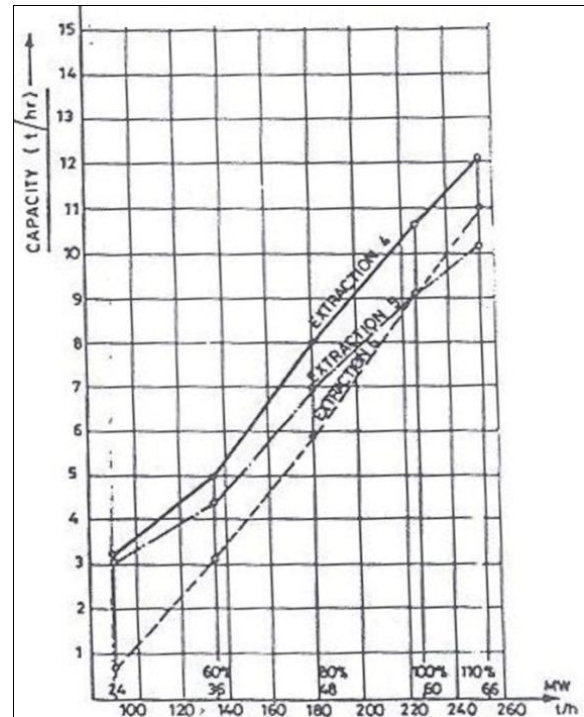
System Parameters	$\eta$	Heat rate KJ/KWh	Final FW temp(°C)	FW Final enthalpy (kJ/kg)	Net work (kJ/kg)	Heat supplied (kJ/kg)
With all HPHs in service	29.38	12253.23	210.9	904.7	736.18	2505.5
With HPH-1 out of service	28.11	12806.8	163.9	786.4	762.66	2713.12
With HPH-2 out of service	28.12	12802.8	172.6	729.2	752.15	2655.9
With all HPH out of service Unit A	27.84	12932.63	150.02	681.3	779.29	2799.52
With all HPH out of service Unit B	27.5	13090.9	136.38	573.65	779.1	2837.51

## 6. CONCLUSION

From the aforesaid study taking account of the correction factors applicable on performance factors affecting results given for various turbine load conditions and condenser status with reference to figure – 6 to 12, it may be concluded that the evaluated derated capacity of the unit effectively stood at 70.5 (± 1.13) MWe as gross generated output (considering the deviation curves provided by the manufacturer on marginal error in respect of heat rate calculation and assumption in the evaluation process and aging effect of the units) without any one of the HP heaters in service. An average variation of 0.13% has been considered for emergency drip operation and gland steam leakage effect. A margin of +1% heat rate deviation has been considered for instrumentation uncertainty as per ASME PTC 6 (Rev. 1985). For 1% makeup water flow to condenser, 2% heat rate deterioration is considered. A 2% heat rate loss is considered for unit aging factor.



**Figure 7: Correction curves for change in Ext. steam pressure at various turbine loads (at rated CW Temp- 32 °C at 77MWe.)**



**Figure 8: Correction curves for change in Ext. Steam capacity at various turbine loads (at CW Temp- 32 °C & 77MWe.)**

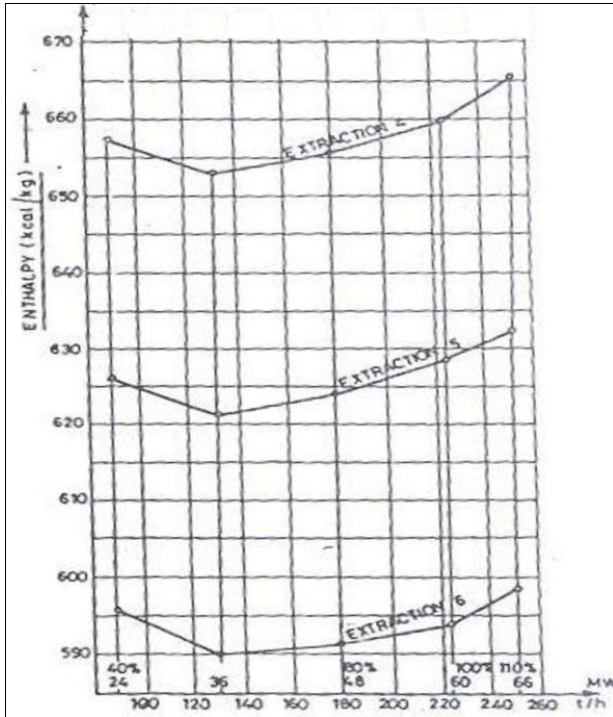


Figure 9: Correction curves for change in Ext. steam Enthalpy at various turbine loads (CW Temp. 32 °C at 77 MWe.)

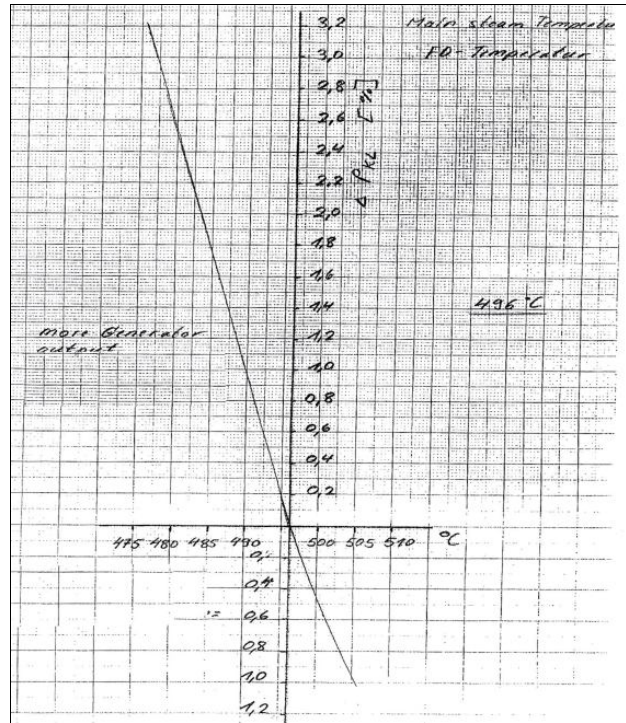


Figure 11: Correction curves of Generator Output for change in turbine inlet steam temperature (CW Temp - 32 °C at 77MWe.)

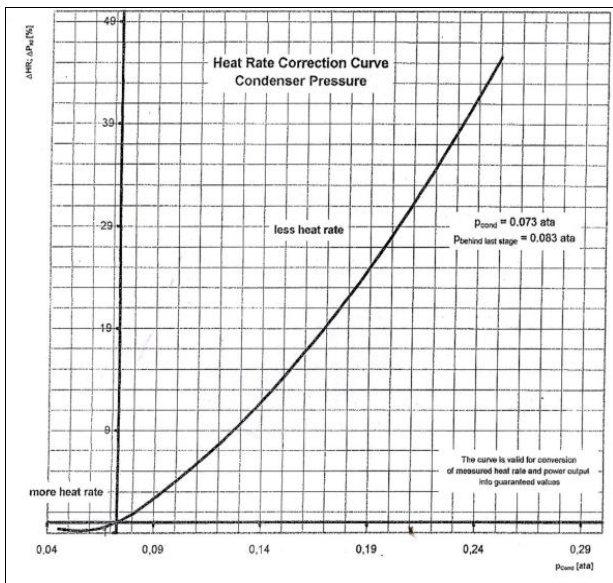


Figure 10: Correction curves of Heat Rate for change in Condenser pressure at various turbine loads (At rated CW Temp- 32 °C at 77MWe.)

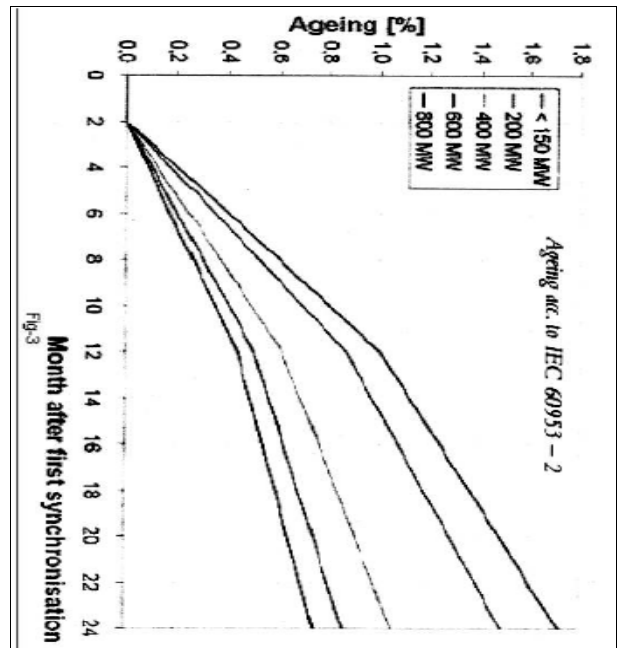


Figure 12: Correction curves of Heat Rate for aging of plant (IEC 60953-2)

## 7. ACKNOWLEDGMENTS

The authors take this opportunity to express sincere thanks to O&M personnel of DPPS/DPL Sri Gautam Ganguly, Sri Gautam Ghosh, Sri Sanjay Das and Sri P. Banerjee (Ex. GM – Power Plant) for their invaluable suggestions extended during project's tenure & also for providing with adequate resources on technical documents during conduction of this project. Sri Bhaskar Dey Sarkar has extended all the desired support and documents on the performance report of PG test of the units after RLA in 2001.

The authors also like to acknowledge support of the colleagues & faculty members and DG-NPTI to accomplish this work. Authors are thankful to the ex. Final year (2011-12) B.Tech (PWE) students Mr. Sayantan Banerjee; Mr. Souvik Mullick; Mr. Kunal Bhattacharjee and Ms.Sreeparna Mukherjee of NPTI-ER who were associated with this project to collect plant data. The project work was funded and sponsored by M/s Durgapur Projects Limited for real time plant performance assessment vide work order no PP/GM(PP)/277/11/11-12/565 Dated : 02.9.11.

## REFERENCES

- [1] Bhattacharya C., Banerjee N.:“Optimizing Boiler Feed Water Inlet Temperature to Maximize Efficiency of Steam Power Plant”; Proc.1st International Conference on Advances in Energy Conversion Technologies, Jan 07-10, 2010.
- [2] Suresh M.V.J.J.; Reddy; K.S. and Kolar A; “Energy and Exergy Analysis of Thermal Power Plants”
- [3] Steam Table (the 1967 IFC Formulation)
- [4] ASME PTC 12.1 – 1978, and PTC 6 (R -1985) Performance test code for closed feed water heaters and instrument measurement uncertainty. The American Society of Mechanical Engineers.



**ANNEXURE:**

<b>Table I-Thermodynamic properties of the working fluid at various states with all heaters in service (from PG test report)</b>								
P(bar)	T(°C)	v (m³/kg)	h (KJ/Kg)	s (KJ/Kg°C)	Sat. point (°C)	State	Ref. state	Location
66.63	497.88	0.0505	3410.25	6.82	282.5	steam	h1	Main steam to turbine
19.21	350	0.1445	3139.3	6.98	210.35	steam	h2	FW Heating steam to HPH-I
19.21	350	0.1445	3139.3	6.98	210.35	steam	h3	HPT Exhaust steam
11.61	292.4	0.218	3030.8	7.02	186.47	steam	h4	FW Heating steam to HPH-II
6	222.1	0.3708	2898.4	7.067	158.83	steam	h5	BFT Heating steam
3.19	171.3	0.6286	2805.2	7.153	135.63	steam	h6	FW Heating steam to LPH
0.61	87.6	2.69945	2656.1	7.53	86.38	steam	h7	FW Heating steam to VH
0.16	55.34	0.001015	2600.7	0.75	55.34	steam	h8	LPT Exhaust steam
0.37	54	0.001014	226.1	0.755	74.02	liquid	h9	CEP inlet
14.86	55.21	0.001014	232.4	0.747	196.91	liquid	h10	CEP outlet
14.41	83.5	0.001031	350.8	1.116	196.39	liquid	h12	Vacuum heater inlet
14.22	103.6	0.001046	435.3	1.346	195.77	liquid	h13	Condensate from VH to LPH
13.77	132.2	0.001071	556.5	1.656	195.18	liquid	h14	Condensate from LPH to D/A
5.57	150*	0.001091	632.2	1.915	155.95	liquid	h15	BFP inlet (*assumed)
105.04	160	0.001095	681.3	1.931	314.64	liquid	h16	BFP outlet
104.88	164.2	0.0011	699.4	1.973	314.48	liquid	h17	FW from HPC2 to HPH-2
104.1	184.2	0.001125	786.2	2.167	313.93	liquid	h18	FW from HPH-2 to HPC1
104.08	185.7	0.001127	792.8	2.181	313.91	liquid	h19	FW from HPC1 to HPH-1
103.6	210.9	0.001165	904.7	2.419	313.57	liquid	h20	FW from HPH-1 to FRS
18	206.6	0.001167	882.2	2.393	207.11	liquid	h21	HPH-1 drip
17.67	197.3	0.001152	840.2	2.305	206.2	liquid	h22	HPC1 drip
11.4	185.1	0.001135	785.6	2.189	185.66	liquid	h23	HPH-2 drip
11.28	176.9	0.001123	749.5	2.109	186.03	liquid	h24	HPC2 drip
2.45	103.6	0.001047	434.4	1.347	126.79	liquid	h25	LPH drip
0.51	77.93	0.001028	326.3	1.051	81.84	liquid	h26	VH drip
<b>Table II- Thermodynamic properties of the working fluid at various states with only HPH-1 out of service</b>								
P(bar)	T(°C)	v (m³/kg)	h (KJ/Kg)	s (KJ/Kg°C)	Sat. point (°C)	State	Ref. state	Location
66.63	497.88	0.050497	3409.5	6.819	282.46	steam	h1	Main steam to turbine
19.21	350	0.14448	3140.2	6.98	210.35	steam	h2	HPT Exhaust steam
11.61	292.4	0.217973	3031.4	7.022	186.48	steam	h3	FW Heating steam to HPH-II
6	222.1	0.370787	2898	7.066	158.84	steam	h4	BFT Heating steam
3.19	171.3	0.628610	2804.5	7.151	135.61	steam	h5	FW Heating steam to LPH
0.61	87.6	2.69448	2656.7	7.53	86.38	steam	h6	FW Heating steam to VH
0.16	55.34	0.001015	2601.6	0.75	55.34	steam	h7	LPT Exhaust steam
0.35	55.0*	0.001015	230.2	0.768	72.71	liquid	h8	CEP inlet(*assumed)
14.86	55.21	0.001014	224.8	0.747	196.91	liquid	h9	CEP outlet
14.41	83.5	0.001031	350.7	1.116	196.39	liquid	h11	Vacuum heater inlet
14.22	103.6	0.001046	435.2	1.346	195.77	liquid	h12	Condensate from VH to LPH
13.77	132.2	0.001071	556.5	1.656	195.18	liquid	h13	Condensate from LPH to D/A
5.57	150	0.339675	632.23	1.915	157.25	liquid	h14	BFP inlet
105.04	160	0.001095	687.45	1.931	314.64	liquid	h15	BFP outlet
104.88	164.2	0.0011	699.4	1.973	314.48	liquid	h16	FW from HPC2 to HPH-2
104.1	184.2	0.001125	786.25	2.167	313.93	liquid	h17	FW from HPH-2 to FRS
11.4	185.1	0.001135	785.7	2.189	185.66	liquid	h18	HPH-2 drip
11.28	176.9	0.001123	429.6	2.109	186.03	liquid	h19	HPC2 drip
1.58	112	0.001054	469.89	1.4405	112.94	liquid	h20	LPH drip
0.53	65	0.00102	272.14	0.894	82.8	liquid	h21*	VH drip

**Derating of 75 MWe PC Fired Power Plant without HP Heaters in Service – A Case Study**

<b>Table III – Thermodynamic properties of the working fluid at various states with only HPH-2 out of service</b>								
P(bar)	T(°C)	v (m³/kg)	h (KJ/Kg)	s (KJ/Kg°C)	Sat. point (°C)	State	Ref. state	Location
66.63	497.88	0.050497	3409.5	6.819	282.46	steam	h1	Main steam to turbine
19.21	350	0.144479	3140.2	6.98	210.35	steam	h2	FW Heating steam to HPH-I
19.21	350	0.14479	3140.2	6.98	210.35	steam	h3	HPT Exhaust steam to IPT
6	222.1	0.370787	2898	7.066	158.84	steam	h4	BFT Heating steam
3.19	171.3	0.628610	2804.5	7.151	135.61	steam	h5	FW Heating steam to LPH
0.61	87.6	2.69448	2656.7	7.53	86.38	steam	h6	FW Htg steam to Vac Heater
0.16	55.34	0.001015	2601.6	0.75	55.34	steam	h7	LPT Exhaust steam
0.15	51	0.001013	213.52	0.71673	53.96	liquid	h8	CEP inlet(*assumed)
14.86	55.21	0.001014	224.8	0.747	196.91	liquid	h9	CEP outlet
14.41	83.5	0.001031	350.7	1.116	196.39	liquid	h11	Vacuum heater inlet
14.22	103.6	0.001046	428.3	1.346	195.77	liquid	h12	Condensate from VH to LPH
13.77	132.2	0.001071	512.87	1.656	195.18	liquid	h13	Condensate from LPH to D/A
5.57	167.23	0.339675	663.4	1.915	157.25	liquid	h14	BFP inlet
105.04	160	0.001095	684	1.931	314.64	liquid	h15	BFP outlet
105.03	161.5	0.001097	687.8	1.946	314.59	liquid	h16	FW from HPC1 to HPH-1
104.55	176.7	0.001115	753.6	2.095	314.25	liquid	h17	FW from HPH-1 to FRS
17.76	206.6	0.001135	785.7	2.189	185.66	liquid	h18	HPH-1 drip
17.44	176.9	0.001123	429.6	2.109	186.03	liquid	h19	HPC1 drip
NA	NA	NA	NA	NA	NA	liquid	h20	LPH drip
NA	NA	NA	NA	NA	NA	liquid	h21	VH drip
<b>Table IV – Thermodynamic properties of the working fluid at various states with both HPHs out of service # Unit A</b>								
66.63	497.88	0.050497	3409.5	6.819	282.46	steam	h1	Main steam to turbine
19.21	350	0.144479	3140.2	6.98	210.35	steam	h2	HPT Exhaust steam to IPT
6	222.1	0.370787	2898	7.066	158.84	steam	h3	BFT Heating steam
3.19	171.3	0.628610	2804.5	7.151	135.61	steam	h4	FW Heating steam to LPH
0.61	87.6	2.69448	2656.7	7.53	86.38	steam	h5	FW Htg steam to Vacuum Heater
0.16	55.34	0.001015	2601.6	0.75	55.34	steam	h6	LPT Exhaust steam
0.15	51	0.001013	213.52	.71673	53.96	liquid	h7	CEP inlet(*assumed)
14.86	55.21	0.001014	224.8	0.747	196.91	liquid	h8	CEP outlet
14.41	89.5	0.001031	350.7	1.116	196.39	liquid	h10	Vacuum heater inlet
14.22	103.6	0.001046	428.01	1.346	195.77	liquid	h11	Condensate from VH to LPH
13.77	132.2	0.001071	537.47	1.656	195.18	liquid	h12	Condensate from LPH to D/A
5.57	147.23	0.339675	609.98	1.915	157.25	liquid	h13	BFP inlet
105.04	160	0.001095	681.3	1.931	314.64	liquid	h14	BFP outlet to FRS
NA	NA	NA	NA	NA	NA	liquid	h15	LPH drip
NA	NA	NA	NA	NA	NA	liquid	h16	VH drip
<b>Table V – Thermodynamic properties of the working fluid at various states with both HPHs out of service # B</b>								
71.44	497.31	0.0469368	3403.63	6.78102	287.21	steam	h1	Main Steam to Turbine
3.93	203.31	0.548218	2868.2	7.1956	142.99	steam	h3	Deaerator/BFT heating Steam
1.78	158.12	1.10275	2787.35	7.37669	116.59	steam	h4	F/W heating Steam to LPH
0.16	73.81	9.97398	2636.46	8.09072	55.34	steam	h5	F/W heating Steam to Vacuum heater
0.15	55.31	10.0201	2598.28	8.00708	54.0	steam	h6	LPT Exhaust Steam
0.36	55.31	0.00101471	231.553	0.771973	73.37	liquid	h7	CEP inlet(*assumed)
15.65	58.99	0.00101587	248.045	0.817146	200.31	liquid	h10	FW to Vacuum Heater inlet
15.35	69.38	0.00102171	291.699	0.946664	199.39	liquid	h11	FW to LPH inlet
15.05	115.31	0.00105542	484.861	1.47588	198.45	liquid	h12	FW to Deaerator inlet
3.1	134.62	0.00107427	566.12	1.68322	134.66	liquid	h13	FW to BFP inlet
1.183	104.38	0.00104694	437.655	1.35642	198.45	liquid	h15	LPH Drip
0.221	62.25	0.00101834	260.6	0.859465	104.4	liquid	h16	Vacuum Heater Drip