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# Performance analysis of steam turbine in Thermal Power plant

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*ABSTRACT*

The analysis of performance of the steam turbine has been carried out and the heat rate is calculated to find out the deviation between the design and the trend in the present operation condition so that the losses can be reduced in order to obtain better efficiency. Here we have calculated Gross Heat rate and Turbine cycle rate and also considered the losses in high energy drains. This analysis helped in predicting the turbine efficiency deterioration level and listed out the preliminary cause of deterioration.

Keywords — *Heat rate, turbine performance, efficiency, Steam turbine, deterioration level.*

## I. Introduction

Steam turbine is the heart which plays a vital role in the power generation as it converts kinetic energy into mechanical energy. The efficiency is determined by the ability to convert all the input work into output work. However, in real case scenario this condition is not possible as most of the parts have friction and the work is dissipated in form of heat thereby producing only less than 50 percentage of the work it received as input energy. In this analysis, we have discussed how to overcome this efficiency gap and produce the maximum possible efficiency of the turbine. Here we have collected several working parameters and the actual efficiency of the turbine was calculated. By these calculations, we have characterised and suggested the improvement techniques to be opted to improve the efficiency of the turbine.

## II. Purpose

Performance monitoring is performed to reduce the heat rate gaps which occurred over period of time and take corrective measures to reduce those gaps to improve the efficiency. Here we have identified and found out the heat rate deviations from the design data available. Then the cause(s) of heate rate gaps are identified by using fault trees or other resources. The equipment operators by their experience should be aware of equipment deterioration and suitable corrective action should be taken prior to impacts the heat rate. This type of pro-active approach should be accomplished by identifying key “primary process indicators”. If this is done, the improvement in higherlevel performance parameters (heat rate, availability, etc.) will follow.

The purpose of monitoring primary process indicators is also to assist data validation/instrument drift and its calibration need**.** By closely monitoring critical instruments, drifts or irregularities can be quickly identified and the instrument can be calibrated or replaced.

## III. Identification of Parameters

List of parameters to be monitored, for the deviation is identified. The parameters which are utilised for the PG and routine tests are selected and then analysed. In most cases back pressure could be the major cause of heat rate degradation. Under rare case scenario back pressure could affect the units overall efficiency. Here deviation on account of HP and IP turbine goes unnoticed due to lack of feedback. So we have listed out the Effect of critical parameters on heat rate.

TABLE 1

**Critical parameters for performance calculation**

| **S.No.** | **Parameter** | **Deviation** | **Effect on Heat Rate** |
|---|---|---|---|
| 1. | Main Seam Temp. | -5 deg.C | +2.3 kcal/kWh |
| 2. | Main Steam Press | -1 $Kg/cm^2$ | +1 kcal/kWh |
| 3. | Reheat Temperature | -5 deg. C | +2.3 kcal/kWh |
| 4. | Reheat Spray | +1% (MS Flow) | +3.0 kcal/kWh |
| 5. | Condenser Back Press | +1 mmHg(a) | +2.0 kcal/kWh |
| 6. | HPT Efficiency | - 1% | +4 kcal/kWh |
| 7. | IPT Efficiency | - 1% | +3 kcal/kWh |

| | | | |
|---|---|---|---|
| 8. | Excess O2 | +1% | +7.2 kcal/kWh |
| 9. | Flue Gas Temperature | +5oC | +4.6 kcal/kWh |
| 10. | DM Make-up | +1% | +17 kcal/kW |

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## IV. CYCLES USED IN STEAM TURBINE

Thermal power plant is working based on the principle of rankine cycle. The fuel used to transfer the thermal energy generated by combustion from boiler to turbine is water, which is vapour is and superheated in boiler (1-7) & re heater(8-9)and subsequently expanded in turbine ( 7-8 HP Turbine, 9-11 IP&LP Turbine ) where it yields its thermal energy, producing the energy necessary to drive the generator. The exhaust steam is condensed in condenser (11-1)

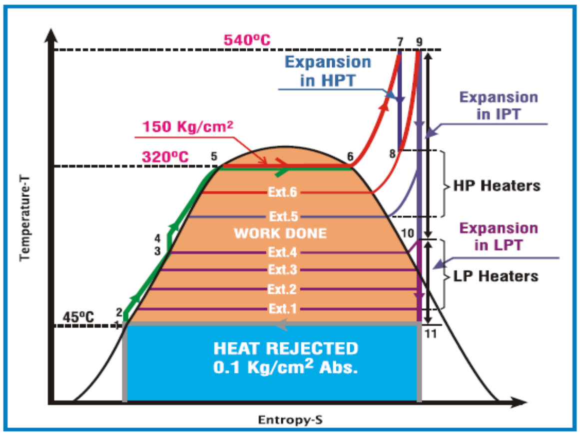


Fig 1: Rankine cycle

The equipment through which water flows to do its work makes a closed circuit which is called thermal cycle. This equipment following the path of water is as follows.

| | |
|---|---|
| 1-2 | Condensate Extraction Pump work |
| 2-3 | Heat added in Low Pressure Heaters |
| 3-4 | Boiler Feeding Pump |
| 4-5 | Heat added in High Pressure Heater |
| 5-6 | Boiler Drum |
| 6-7 | Super Heater |
| 7-8 | High Pressure Turbine |
| 8-9 | Reheater |
| 9-10 | Intermediate Pressure Turbine |
| 10-11 | Low Pressure Turbine |
| 11-01 | The exhaust steam is condensed in condenser |

### A. Types Of Blades:

Based on the application Blades are classified as follows

1) Pressure at stages

- HP BLADES (high pressure blades)
- IP BLADES (intermediate pressure blades)
- LP BLADES (low pressure blades)

2) Their function in the turbine
Steam turbine moving blades

- Blades from the bar stock
- Rhomboid blades
- Curved blades
- Twisted profile blades
- Drawn profile blades

## V. OVERALL EFFICIENCY CALCULATION

### A. Mass flow rates

<u>Feed water flow at HP Heater 7 Outlet</u>

$\mathbf{m_{14} = m_{10} + m_{13} + m_9 - m_{20} - m_{21}}$

$m_{14} = 536+74.62+24.78+26.25+0.2$

$\mathbf{m_{14}=615.65\ kg/m^3}$

<u>HP heater 6 Drain flow</u>

$\mathbf{m_{13}=m_{15}+m_{12}}$

$m_{13} = 43.12+34.37$

$\mathbf{m_{13}=77.49\ kg/m^3}$

### B. HP Heater 6, HP heater 7 steam flow

<u>Heat balance around HP Heater 7</u>

$\mathbf{m_{15}(h_{15}-h_{23}) = m_{14}(h_{14}-h_{24})}$

$m_{15} = m_{14}(h_{14}-h_{24})/(h_{22}-h_{23})$

$m_{15} = 615.65*(1051.98 - 910.77312)/(3089 - 932.61)$

$\mathbf{m_{15}= 43.12\ kg/m^3}$

<u>Heat balance around HP heater 6</u>

$\mathbf{m_{12}(h_{12}-h_{13}) = m_{15}(h_{13}-h_{23})+m_{14}(h_{25}-h_{25a})}$

$m_{12}=m_{14}(h_{25}-h_{25a})+m_{15}(h_{13}-h_{23})/(h_{12a}-h_{13})$

$m_{12} = 673.19*(910.77 - 767.26) + 40.25(789.60 - 932.61)/(3356 - 789.60)$

$\mathbf{m_{12} = 35.40\ kg/m^3}$

### C. Deareator Steam flow

Heat balance around the deareator

$$\mathbf{m_{11} . h_{11} = m_{10} . h_{10} + m_{26}. h_{26} + m_{13}. h_{13}}$$

$m_{26}=(m_{11} . (h_{11}-h_{10}) + m_{13}. (h_{10}-h_{13}))/(h_{26}-h_{10})$

$m_{26}$ = 536.34*(751.06 – 932.61) +789.604 *(932.61 – 789.60)/ (3167 – 932.61)

$$\mathbf{m_{26} = 6.95\ kg/m^3}$$

D. **Spray water flow to auxiliary steam**

Heat balance around the desuperheater

$$\mathbf{m_{21} . h_{21} + m_4 . h_4 = m_{19} . h_{19}}$$

$m_{19}= m_{21}+ m_4$

$m_{21} = (m_4. (h_4 – h_{19}))/(h_{19}-h_{21})$

$m_{21}$ = 5*(3077 – 682.02) / (682.02 - 0)

$$\mathbf{m_{21} = 17.55\ kg/m^3}$$

Main steam flow

$$\mathbf{m_1= m_{14}– m_8- m_{Lboiler}- m_{LPH}}$$

$m_1$= 614.89 + 0.76 + 0 + 0

$$\mathbf{m_1= 615.65\ kg/m^3}$$

Hot reheat mass flow to I.P. steam turbine inlet($m_5$)

$$\mathbf{m_5 = m_3 + m_{21}}$$

$m_3$ = 563.77 + 0.2

$$\mathbf{m_3 = 563.97\ kg/m^3}$$

E. **Heat rate calculation**

$$\mathbf{Heat\ rate=\{[(m_1*h_1)-(m_{14}*h_{14})+(m_3(h_5-h_3))+(m_{21}(h_5-h_{21}))+(m_7*h_7)-(m_4*h_4)]*3600\}/P_g}$$

Heat rate ={ [ (615.65*812.47) – (615.65* 251.43) + (563.77*(843.57-742.87)) + (24.78*(843.57-182.38)) + (12.96* 36.02) – (4*738.70) ] *3600/ 214.29 }

**Heat rate = 2135.7 Kcal/KWhr**

F. **Total cycle efficiency**

$$\boldsymbol{\eta = P_g/\text{Heat supplied}}$$

$\eta$ = 214.29*1000/493418

$$\boldsymbol{\eta = 43.429\%}$$

## VI. TYPICAL COST IMPLICATION OF 1 KCAL/KWH HR DEVIATION

Assumption :

GCV of coal : 2600 kcal/kg
Coal cost : Rs 1950 per ton
Plant load factor : 82%
Load capacity : 210 MW
Power Generation : 1508.47 MW = 1508,470,000 KWh (82% PLF)

1 kcal/kwh improvement in HR can save 1508,470,000 kcal in a year.

Coal saved in a year = 1508,470,000 kcal / 2600 kcal/kg = 580,180 kg/year (GCV 2600 kcal/kg)
= **580.18 MT Coal = Rs 11,31,000**
(Cost of coal = Rs 1950 / Tonne)

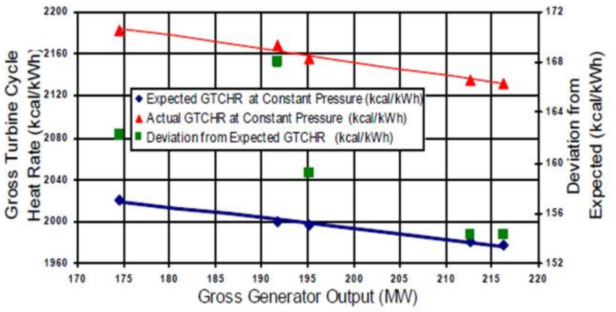


**Fig 2: Gross turbine cycle heat rate vs Gross generated output**

## VII. PLANT PERFORMANCE INDICES: HEAT RATE

The heat rate of the coal fired power plant is the measure of efficient conversion of chemical energy in to electrical energy. If the power plant operates at 100% efficiency, the Heat rate will be 860 kcal/kwh. Currently, a state of art this power plant has a design heat rate od 2100 – 2200 kcal/kwh ie. About 39 to 41 percentage but in our analysis we get the heat rate of 38.2 prcentage so the gap in the heat rate loss will account in the efficiency.

## VIII. TURBINE EFFICIENCY GAP

**Typical values of efficiency**

HP 86 %
IP 90 %
LP 80 %

LP Turbine efficiency is lower due to moisture content in last stages. 1% increase in moisture content effects 1% stage efficiency.

Table II
**List of turbine efficiency losses**

| Breakup of Turbine Efficiency Losses (%) | |
|---|---|
| Leakage loss | 50% |
| Surface roughness | 36% |
| Others | 14% |

A. Turbine Surface roughness

1) Surface finish degradation:
- Deposits
- Corrosion
- Solid particle erosion
- Mechanical damage

Roughness upto 0.05 mm can lead to decrease in efficiency by 4%

Table III

**Design Heat rate and actual Heat rate**

| Design kcal/kwh | Actual kcal/kwh | Total losses Kcal/kwh |
|---|---|---|
| 1981 | 2135.7 | 154 |

Accountable loss: 127kcal/kwh
Unaccountable loss: 27 kcal/kwh

B. **Accountable losses**

| Description | Loss in kcal/kwh |
|---|---|
| HP turbine Eff. | 16 |
| IP Turbine efficiency | 31 |
| Cond. Vac. | 32 |
| HP. Heater 5 &6 | 42 |
| RH Temp | 6 |

C. **Unaccountable losses**

Losses are nominal losses
- Passing through high energy drains.
- LP. Turbine performance.
- LP. Heaters.
- Uncertainity of Instruments.

TABLE IV

**Typical losses**

| Typical Turbine/generator losses | |
|---|---|
| Nozzle and bucket aerodynamic losses | 3.7% |
| Exhaust losses | 1.3% |
| Turbine Pressure drop | 0.2% |
| Bearing and windage | 0.2% |
| Leakage | 0.3% |
| Generator electrical losses | 6.1% |

## IX. FAULT ANALYSIS

In fault analysis carried out we came into conclusion that the heater tubes were fouled either in steam or water side as an effect of moisture content present in the steam and water.

There may be various internal leakages through the water box partition plate in the pipeline of the steam carry over tubes.

External leakages through by pass valve is the major problem as if there is more heat generated than the required amount then these are passed away through the bypass valves.

Plugged tubes and air blanketing is the major causes of reduction in the efficiency, as well as the pressurised sir and the high temperature drainage defects also contribute to the reduce in the efficiency.

## X. CONCLUSION

A Performance analysis of Turbine in thermal power plant is carried out to emphasise on the efficiency. The results are analyzed for mass flow rates, temperature and pressure distributions on blades, power developed by stage and isentropic efficiency of the stage.

Under review, the analysis revealed that the average overall efficiency was 43.49% (43.13% minimum; 43.75 maximum) as against expected values of 44-45%.

The reasons for the lag in the insentropic efficiency of the turbine and overall power plant has been listed out. These include:

Drain Line Passing: This is a silent loss because it does not appear in parameters. Monitoring is done by temperature measurement on downstream (flash tank) side which is supposed to be cold.

Main Steam Pressure: Results into throttling loss.

Hot Reheat Temperature: Sometimes it is not possible to maintain hot reheat temperature due to variation in fuel calorific value and there is loss.

It is important to be the low cost power producer for the future generation. Power plant Engineers can make a significant contribution toward achieving this goal by implementing a well-organized performance monitoring program which will reduce fuel costs and facilitate cost-effective maintenance.

Uniform formats for performance reporting to generate a reliable database for cost effective maintenance and improvement to develop requsite skills reducing the auxiliary unit power comsumption will also contribute the part in increasing the efficiency of the power plant.

Routine performance tests to be carried out with the special instruments duly calibrated and also testig with atmost precision can formulate the accurate results and there by reducing the unaccountable losses.

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**Biographies and Photographs**

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