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Effect of condenser vacuum on performance of a Reheat Regenerative 210 MW Fossil-Fuel based Power Plants.

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***Abstract--* The thermal power plants are used to generate power. In this study, the analysis has been applied to the typical 210MW (LMZ) plant in India. Designed of thermal power plant is based on conditions (like a good quality of steam, pressure and temperature of steam etc.), but actual outlet conditions are not as per the designed values. In practical, when power plants are installed there are lots of constraints. It has been observed that the design specified condenser vacuum is not maintained in most of the Indian thermal power stations, consequences of which invariably remain the poor efficiency, more costly generation and financial burden to the consumers. This paper deals with the factors or parameters which reduced the efficiency of the condenser.**

***Keywords* – Condenser Vacuum, Cooling Water**

I. INTRODUCTION

India's energy market is one of the country's fastest developing sectors. Annual demand for electricity has increased from 1713 MW in 1950 to 2,25,793.10 MW(31.06.2013).The electricity generated from thermal power plants constitutes 68.14 % of total generation. The availability of coal in the country is such that the higher grades of coal, which have higher calorific value, have been exhausted and progressively lower grades of coal are being made available for generation of electricity in power plants. This had resulted in poor thermal efficiencies of power plants.

The condenser is a heat transfer device or unit used to condense a substance from its gaseous to its liquid state, typically by cooling it. In doing so, the latent heat is given up by the steam, and will transfer to the condenser cooling water. The main use of a condenser is to receive exhausted steam from a steam engine or turbine and condense it into the water by extracting the latent heat and condenses the steam to a pressure significantly below atmospheric. This allows the turbine or engine to do more work. The condenser also converts the discharge steam back to feed water which is returned to the steam generator or boiler. [1] In practical situations, when power plants are installed there are lots of constraints. This tends to reduce or increase output power and heat rate of thermal power plants. Due to these conditions, the designed power and heat rate are never achieved. [2-5] The calculated thermal efficiency was 38.39 % while the exergy efficiency of the power cycle was 45.85%. [6]

II. DESCRIPTION

Basically, a condenser is a device where steam condenses and latent heat of evaporation released by the steam is absorbed by cooling water. Thermodynamically, it serves the following purposes with reference to the P-v diagram shown in Figure 1. Firstly, it maintains a very low back pressure on the exhaust side of the turbine. As a result, the steam expands to a greater extent and consequently results in an increase in available heat energy. The shaded area shown in the P-v diagram exhibits the increase in the work obtained by fitting a condenser unit to a non-condensing unit for the same available steam properties. In the P-v diagram,

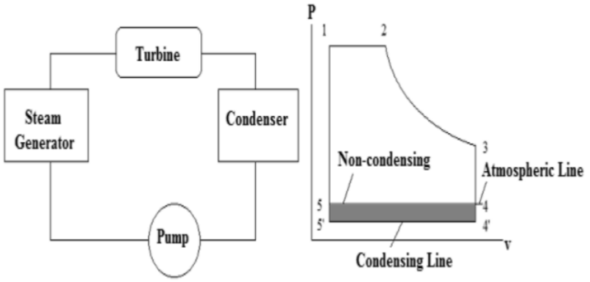

Figure 1: Key components of a thermal power plant working on a Rankine Cycle [7]

In figure line 4-5 is non-condensing line when the condenser unit is not applied and line 4“-5“ is a condensing line when the condenser is used. Secondly, the exhaust steam condensate is free from impurities. Thermal efficiency of a condensing unit is higher than that of a non-condensing unit for the same available steam properties. In a reciprocating steam engine, the condenser pressure can be reduced to about 12 to 15 cm. of Hg. The thermodynamic analysis of condensate application is discussed in a thermal power plant using regenerative Rankine cycle with a closed feed water heater and pumped condensate is pumped from the condenser through the Feed Water Heater (FWH) directly to the steam generator and to the turbine. As the initial pressure at the inlet of turbine is fixed and operating pressure of the condenser is low due to an increased vacuum, the enthalpy drop of the expanding steam in the turbine will increase. This increases the amount of available work from the turbine. The low condenser operating pressure enables higher turbine output, an increase in plant efficiency and reduced steam flow for a given plant output. It is, therefore, advantageous to operate the condenser at the lowest possible pressure (highest vacuum).[10-12] The condenser provides a closed space into which the steam enters from the turbine and is forced to give up its latent heat of vaporization to the cooling water. It becomes a necessary component of the steam cycle as it converts the used steam into water for boiler feed water and reduces the operational cost of the plant. Also, efficiency of the cycle increases as it operates with the largest possible delta-T and delta-P between the source (boiler) and the heat sink (condenser). As the steam condenses, the saturated liquid continues to transfer heat to the cooling water as it falls to the bottom of the condenser, or hot-well. This is called sub-cooling, which is desirable up to a certain extent.

The difference between the saturation temperature for the existing condenser vacuum and the temperature of the condensate is termed condensate depression. [13, 14] This paper deals with analysis and examine of some potential parameter directly influence the condenser vacuum, which can be satisfactorily managed by maintaining the optimized values of the other performance parameters. Some of such parameters are mentioned here under;

2.1 Cooling Water Inlet Temperature

High cooling water inlet temperature (t_1) leads to higher saturation temperature and corresponding rise in condenser saturation pressure (i.e. lower condenser vacuum) for a design specified cooling water temperature rise and terminal temperature difference. As the t_1 is an uncontrollable parameter for a once through type of cooling water system and hence required to be incorporated in the other controllable operating parameters such as rise in cooling water flow subjected to maximum critical erosion limits, reduction of load not more than that corresponding heat loading, operating parameters of vacuum creating devices. In addition to the above (t_1) is attempted to be minimized through the cooling towers in which heat of cooling water is rejected to ambient air.

These are two effects caused by the cooling water inlet temperature. The primary one is to alter the steam saturation temperature by the same amount as the change, assuming all the other factors remain constant. This, in its turn, will change the corresponding back pressure. The secondary effect is caused by the fact that the heat transfer of the cooling water film in contact with condenser tubes change with temperature of the water. The primary and secondary changes are in opposite direction. The magnitude of the secondary effect is approximately equal to the fourth root of the mean cooling water temperature.

Table 1
Effect of Variation in Cooling Water Inlet Temperature on Condenser Vacuum

SNo		Q_s	Q_{cw}	t_1	t_2	T_s	t_2-t_1	TTD	LMTD
	design	435680	25730825	30	40	46	10	6	10
1	High t1	435680	25730825	32	41.3	46.1	9.32	4.78	10
2		435680	25730825	34	43.3	48.2	9.32	4.88	9.9
3		435680	25730825	36	45.3	50.3	9.32	4.98	9.8
4		435680	25730825	38	47.3	52.4	9.32	5.08	9.7
5		435680	25730825	40	49.3	54.5	9.32	5.18	9.6
	design	435680	25730825	30	40	46	10	6	10
6	low t1	435680	25730825	28	37.3	41.9	9.32	4.56	10
7		435680	25730825	26	35.3	39.8	9.32	4.44	11
8		435680	25730825	24	33.3	37.6	9.32	4.31	11
9		435680	25730825	22	31.3	35.5	9.32	4.18	11
10		435680	25730825	20	29.3	33.4	9.32	4.05	11

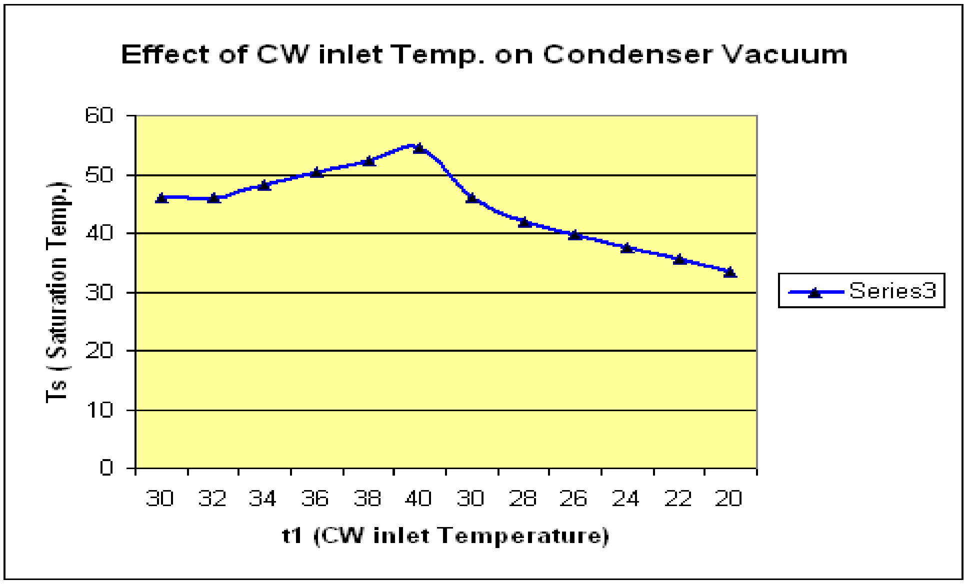

Figure 2: effect of CW inlet temp on condenser vacuum

2.2 Cooling Water Flow

Reduced cooling water flow shall increase the cooling water temperature rise, which leads to higher saturation temperature at design terminal temperature difference and corresponding saturation pressure. Cooling water pressure drop across the condenser tubes reduces the cooling water flow.

Higher pressure drop indicates internal tube surface deposits, which adversely affects the cooling water flow and heat transfer. Adequate flow can be maintained by higher discharge pressure but heat transfer shall remain condenser vacuum control parameters. A frequent on line tube cleaning and proper condenser maintenance can help.

The primary effect of a change of cooling water flow is to alter its temperature rise. The secondary effect, which operates in the same direction as the primary, results from the change of heat transfer rate, due to the changed thickness of the cooling water boundary film. It is approximately proportional to the square root of the flow.

Table 2
Effect of Variation in Cooling Water flow on Condenser Vacuum

SNo		Q_s	Q_{cw}	t_1	t_2	T_s	t_2-t_1	TTD	LMTD
	design	435680	25730825	30	40	46	10	6	10
1	highCW	435680	26245442	30	39.8	45.2	9.8	5.45	10
2		435680	26770350	30	39.6	44.9	9.61	5.26	10
3		435680	27305757	30	39.4	44.5	9.42	5.07	9.9
4		435680	27851872	30	39.2	44.1	9.24	4.89	9.8
5		435680	28408910	30	39.1	43.8	9.06	4.72	9.7
	design	435680	25730825	30	40	46	10	6	10
6	low CW	435680	25216209	30	40.2	46.5	10.2	6.33	9.8
7		435680	24711884	30	40.4	47	10.4	6.56	9.9
8		435680	24217647	30	40.6	47.4	10.6	6.8	10
9		435680	23733294	30	40.8	47.9	10.8	7.04	10
10		435680	23258628	30	41.1	48.4	11.1	7.3	10

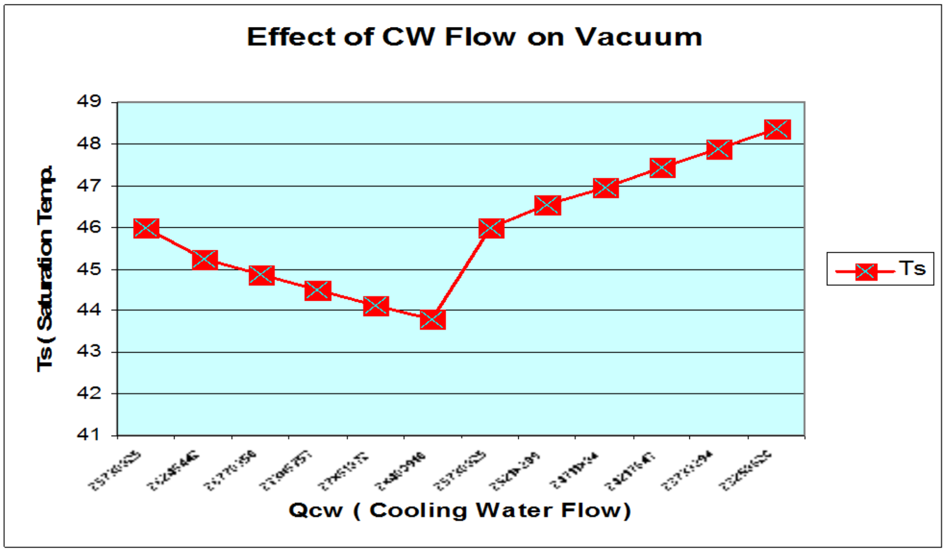

Figure 3: effect of CW flow on condenser vacuum

2.3 Change in Heat Transfer

Change in heat transfer due to any reason, proportionately changes the condenser vacuum, which is briefly described here under;

2.3.1 Level in Condenser Hot Well

Level more than that of the design value, covers some of tubes and make them unavailable for condensation.

Condenser vacuum falls in similar way as in case of inadequate cooling water flow followed by significant sub cooling. Condensate pumps and associated condenser hot well control system must be maintained healthy enough to keep the condensate level within design specified ranges.

2.3.2 Steam Flow

Increasing steam flow shall increase the saturation temperature at and corresponding saturation pressure.

Steam flow is a very important input parameter which is regulated as per the requirement of electricity demand. Load raising should preferably be restricted within the condenser capability limit to prevent wastage of heat at higher potential.

2.3.3 Internal/External Tube Deposits

Dirty condenser tubes reduce the heat transfer, which adversely reflects upon condenser vacuum.

Table 3
Effect of Variation of load on Condenser Vacuum

SNo		Q_s	Q_{cw}	t_1	t_2	T_s	t_2-t_1	TTD	LMTD
	Design	435680	25730825	30	40	46	10	6	10
1	HighQs	444394	25730825	30	40.2	46	10.2	5.76	10
2		453281	25730825	30	40.4	46.3	10.4	5.87	11
3		462347	25730825	30	40.6	46.6	10.6	5.99	11
4		471594	25730825	30	40.8	46.9	10.8	6.11	11
5		481026	25730825	30	41	47.3	11	6.23	11
	Design	435680	25730825	30	40	46	10	6	10
6	LowQs	426966	25730825	30	39.8	45.3	9.8	5.53	10
7		418427	25730825	30	39.6	45	9.6	5.42	9.8
8		410059	25730825	30	39.4	44.7	9.41	5.31	9.6
9		401857	25730825	30	39.2	44.4	9.22	5.21	9.4
10		393820	25730825	30	39	44.1	9.04	5.1	9.2

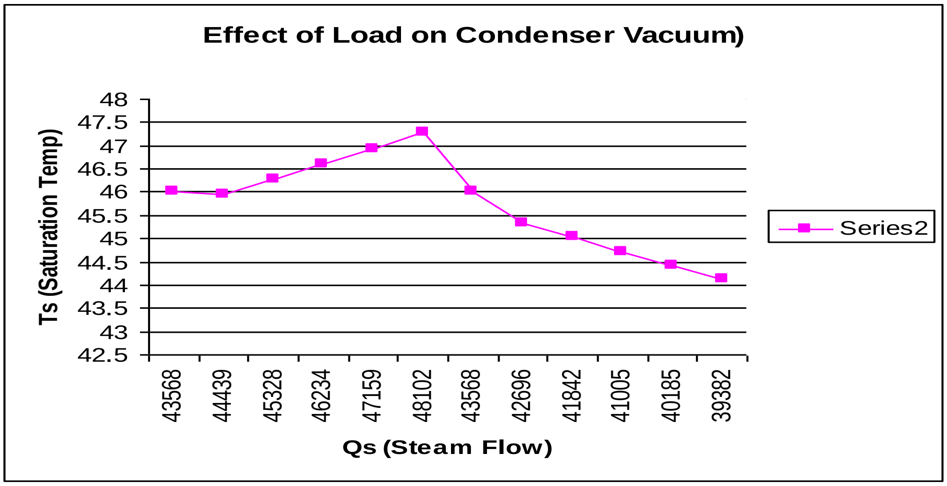

Figure 4: effect of load on condenser vacuum

2.3.3 Operating Parameters of Vacuum Creating Devices

The non-condensable are required to be removed continuously by the effective vacuum creating devices (i.e. Steam ejectors or vacuum pumps), mal operation of which reduce vacuum. Starting ejector can create vacuum up to 540 mmHgCl. In addition to relying upon design specified vacuum value of the starting ejector, it is better to sufficiently wait till its capacity is exhausted and stable vacuum is maintained. 10 to 30 minutes after the establishment of stable vacuum by starting ejector, the main ejector should be cut into service followed by immediate withdrawal of starting ejector. Parallel operation of both the ejector shall not only develop the lesser vacuum but also damage the main ejector.

2.3.4 Terminal Temperature Difference

Causes and remedial measures of the higher terminal temperature difference are briefly mentioned here under;

a) Higher gaseous impurities in the steam can be managed by better management of boiler and pre-boiler system
b) Air ingress can be avoided by frequent leak detection test and effective steam sealing of low pressure turbine
c) External tube deposits can gradually increase terminal temperature difference which needs better de mineralized water quality management
d) Internal tube deposits causing higher terminal temperature difference with higher cooling water pressure across the condenser can be effectively minimized by on-line condenser tube cleaning.

2.4 Concluding Remarks

Feasibility analysis of the potential parameters reveals that the managerial determination blended with right men and material can improve the performance of the thermal power stations. Sufficient guide lines have been provided to the user to quantify the loss under the prevailing operating conditions and broadly analyze and divide the same distinctly either as inevitable or as avoidable so that the all improvement efforts can be made in right direction.

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