A REVIEW ON THERMODYNAMIC ANALYSIS OF THERMAL POWER PLANT

Gohel Ketankumar Nathalal,

Lecturer in Mechanical Engineering,
Government Polytechnic, Porbandar, Gujarat, India.

Abstract: Thermal power plants are one of the most important process industries for engineering professionals. Over the past decades, the power sector is facing a number of critical issues; however, the most fundamental challenge is meeting the growing power demand in sustainable and efficient ways. The present paper gives a brief introduction of Coal fired thermal power plant based on Rankine cycle, its characteristic and site selection, Thermodynamic Analysis with flow-sheet computer program like Cycle – Tempo, Performance analysis of plant with different cycles of operation,Thermal analysis of combined cycle power plant, and Exergtic efficiency improvement in the Thermal power plant cycle.

***IndexTerms* – Thermal Power Plant, Rankine Cycle, Combined cycle Power Plant, Exergtic Efficiency.**

1. INTRODUCTION

Thermal power plants are one of the most important process industries for engineering professionals. Today, most of the electricity produced throughout the world is from steam power plants. However, electricity is being produced by some other power generation sources such as hydropower, gas power, bio-gas power, solar cells, etc.
A steam power plant continuously converts the energy stored in fossil fuels i.e. coal, oil, etc. or fossil fuels e.g. uranium, thorium into shaft work and ultimately into electricity. The working fluid is "water" which is sometimes in the liquid phase and sometimes in the vapor phase during its cycle of operations.

A fossil fuelled power plant is an example of bulk energy converter from fuel to electricity using "water" as the working medium. The energy released by the burning fuel is transferred to water in the boiler to generate steam at high temperature, which then expands in the steam at high temperature, which then expands in the steam turbine to a low pressure to produce shaft work. The steam leaving the turbine is condensed into water in the "condenser" where cooling water from a river or sea circulates, carrying away the heat released during condensation. The water (condensate) is then feedback to the boiler by the pump and the cycle goes on repeating itself**. [1]**

Out of total power developed in India about 60% is thermal. For a thermal power plant the range of pressure may vary from 10 kg/cm2 to super critical pressures and the range of temperature may be from 250°C to 650°C. The average all India Plant load factor (P.L.F.) of thermal power plants in 1987-88 has been worked out to be 56.4% which is the highest P.L.F. recorded by thermal sector so far. Installed power station capacity in India as of 30 September 2018 as shown in Table1.1**. [2]**

Table 1.1 Installed power station capacity in India as of 30 September 2018.

Sector	Thermal (mW)				Nuclear (mW)	Renewable (mW)			Total (mW)
	Coal	Gas	Diesel	Sub-Total Thermal		Hydro	Other Renewable	Sub-Total Renewable	
Central	56,955.00	7,237.91	0.00	64,192.91	6,780.00	12,151.42	1,502.30	13,653.72	84,626.63
State	63,596.50	7,048.95	363.93	71,009.38	0.00	29,942.00	2,004.87	31,946.87	102,956.25
Private	75,546.00	10,580.60	473.70	86,600.30	0.00	3,394.00	67,141.44	70,535.44	157,135.74
All India	196,097.50	24,867.46	837.63	221,802.59	6,780.00	45,487.42	70,648.61	116,136.03	344,718.61
Percentage	**56.89**	**7.21**	**0.24**	**64.34**	**1.97**	**13.20**	**20.49**	**33.69**	**100**

1.1 COAL FIRED POWER PLANT

The flow sheet of a thermal power plant consists of the following four main circuits:

- Feed water and steam flow circuit
- Coal and ash circuit
- Air and gas circuit and
- Cooling water circuit.

Fig. 1.1 shows a schematic arrangement of equipment of a steam power station. Coal received in coal storage yard of power station is transferred in the furnace by coal handling unit. Heat produced due to burning of coal is utilized in converting water contained in boiler drum into steam at suitable pressure and temperature. The steam generated is passed through the super heater. Superheated steam then flows through the turbine. After doing work in the turbine die pressure of steam is reduced. Steam leaving the turbine passes through the condenser which maintains the low pressure of steam at the exhaust of turbine. Steam pressure in the condenser depends upon flow rate and temperature of cooling water and on effectiveness of air removal equipment. Water circulating through the condenser may be taken from the various sources such as river, lake or sea. If sufficient quantity of water is not available the hot water coming out of the condenser may be cooled in cooling towers and circulated again through the condenser. Bled steam taken from the turbine at suitable extraction points is sent to low pressure and high pressure water heaters.

Air taken from the atmosphere is first passed through the air pre-heater, where it is heated by flue gases. The hot air then passes through the furnace. The flue gases after passing over boiler and super heater tubes, flow through the dust collector and then through economizer, air pre-heater and finally they are exhausted to the atmosphere through the chimney. **[3]**

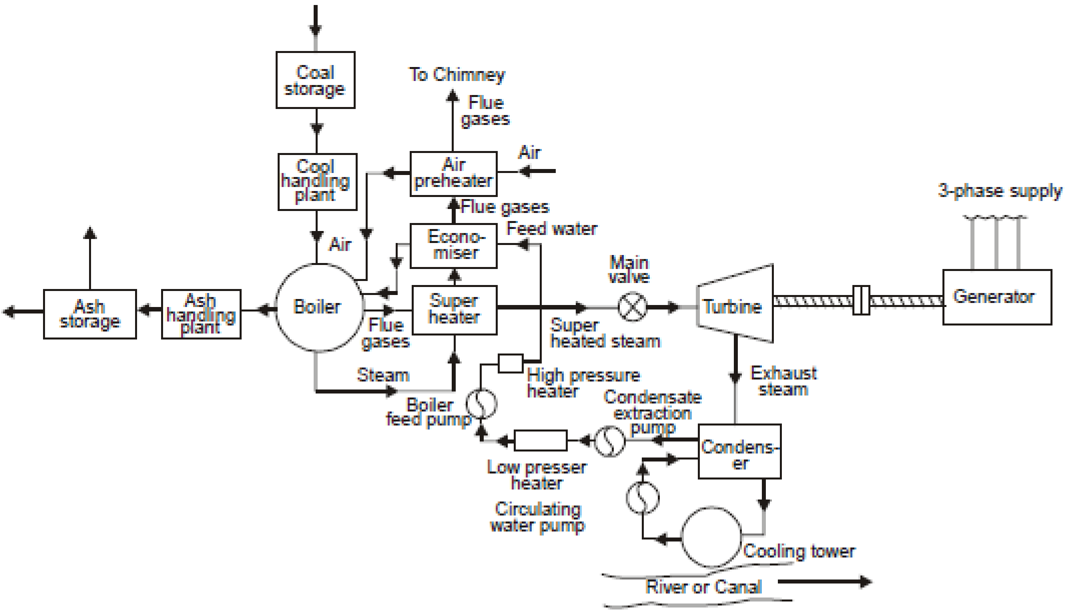
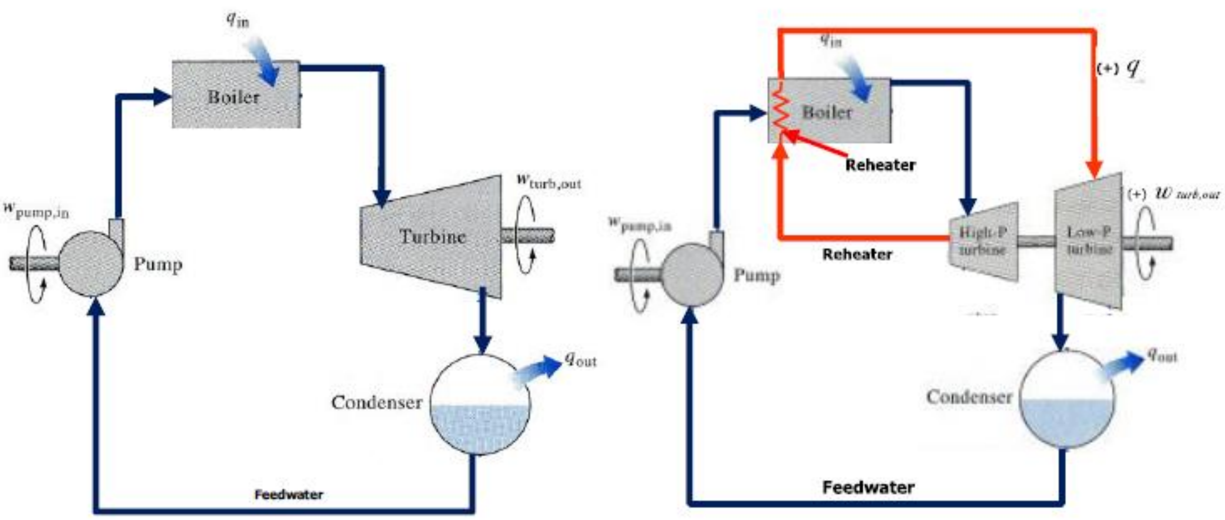


Figure 1.1 *Layout of Thermal Power Plant*

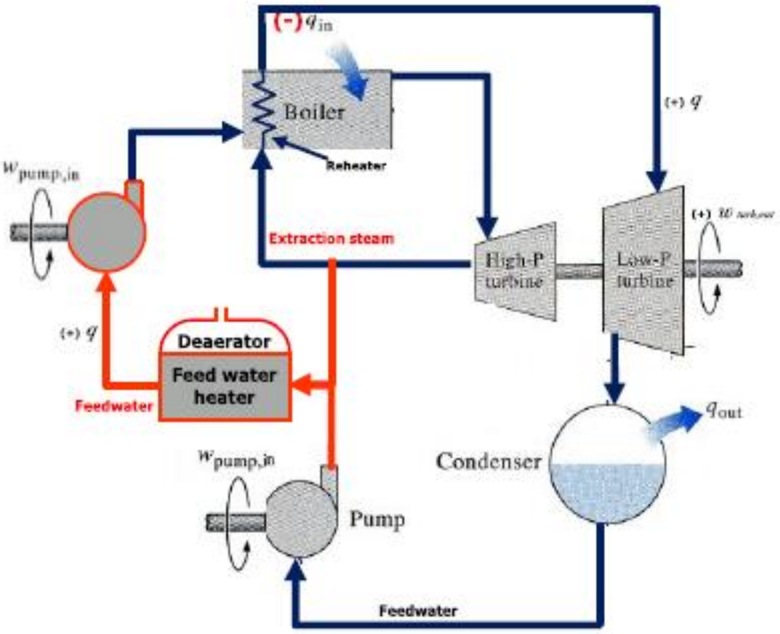
1.2 THERMAL POWER PLANT BASED ON RANKINE CYCLE

In a simple Rankine cycle, steam is used as the working fluid, generated from saturated liquid water (feed-water). This saturated steam flows through the turbine, where its internal energy is converted into mechanical work to run an electricity generating system. All the energy from steam cannot be utilized for running the generating system because of losses due to friction, viscosity, bend-on-blade etc. Most of the heat energy is rejected in the steam condenser. The feed water brings the condensed water back to the boiler.

Concerning coal-fired power plants, the main technical factors and power production of the plant are based on a thermodynamic cycle called the Rankine cycle. This cycle is depicted in Figure 1.2 and consists of a turbine, boiler, pump, and condenser. The thermal efficiency of the Rankine cycle can be increased by a regeneration cycle, reheat cycle, and a combined regenerative reheat cycle. The thermal efficiency can be adjusted by changing factors such as the main steam pressure, the main steam temperature, and the turbine outlet pressure.



(a) Rankine cycle ***(b) Reheat cycle***



(c) Regenerative reheat cycle

Figure 1.2 Simple Steam Power Plant.

The thermal efficiency of the Rankine cycle is the ratio of the specific network output (**$W_{Turbine,Out}$**) and the specific heat input (**Q_{in}**). The thermal efficiency is determined by the steam enthalpy of the turbine inlet and the enthalpy of steam at the turbine outlet. To improve the efficiency of the Rankine cycle, which is the basis of the coal power cycle, the steam temperature and pressure at the turbine inlet and the pressure at the turbine outlet should be optimized.

Increasing the efficiency of the power generating cycle is typically accomplished one of three ways: increasing the boiler pressure, increasing input steam temperature, and/or decreasing condenser pressure. Increasing the main steam pressure at the turbine inlet (boiler) raises the temperature at which boiling takes place, which raises the heat added to the steam. Though an efficiency solution, it also increases the system pressure (increasing condenser pressure) and increases the wet steam at the turbine outlet, which equates to turbine blade corrosion and reduces efficiency. A reheat cycle in which a second turbine and reheat-cycle are added mitigates these inefficiencies. With the reheat cycle, there is no wet steam build up at the high-pressure turbine outlet and the larger second turbine (requires less pressure, so-called low-pressure turbine) decreases the damages caused by moisture and has a lower pressured output, which increases system efficiencies.

The next option to increase efficiency is raising the heat of the boiler's steam input. As the temperature of the feed water is raised, the amount of heat input required of the boiler is reduced. A feed water heater is used to heat the wet steam leaving the condenser (feed water) and the steam that is expanding in the turbine (extraction steam). This system is called the regeneration cycle (Figure 1.2 (c) and includes a deaerator for heating and removing air and several low and high-pressure feed water heaters. The cycle efficiency is improved by increasing the number of feed water heaters. However, in practice, the optimum number of feed water heaters is determined by considering the economics**. [4]**

1.3 CHARACTERISTICS OF STEAM POWER PLANT

The desirable characteristic for a steam power plant are as follows:

- Higher efficiency.
- Lower cost.
- Ability to burn coal especially of high ash content and inferior coals.
- Reduced environmental impact in terms of air pollution.
- Reduced water requirement.
- Higher reliability and availability.

1.4 CHOICE OF SITE FOR THERMAL POWER STATIONS

In practice, the following points should be considered in order to decide the location of the power station to achieve overall economy.

- Cost and Type of Land.
- Availability of Water.
- Supply of Fuel.
- Cost of Fuel.
- Nearness to Load Centre.
- Distance from Populated Area.
- Ample Space.
- Disposal of Ash.
- Interest of National Defence.

2. THERMODYNAMIC ANALYSIS OF EXISTING COAL FIRED CONVENTIONAL STEAM POWER PLANT USING CYCLE TEMPO

M K Pal, H. Chandra and A Arora [5], carried out a Thermodynamic Analysis of a 250 MW Coal-fired conventional steam power plant located in Rihand Super Thermal power plant, Rihand nagar Distt. Sonbhadra (U.P.) The thermodynamic performance of the power plant is estimated by a system simulation. A flow-sheet computer program, **"Cycle- Tempo"** is used for the study. In addition, detailed exergy losses were illustrated and describe the temperature profiles for the main plant components.

The Analysis results were verified against data gathered from the log sheet obtained from the station during its operation hours. The power plant system was simulated and a detailed parametric study was undertaken, which involved environmental parameters, such as the temperature of cooling water entering the condenser and the inlet ambient air temperature, as well as some other operational parameters, such as excess air percentage and stack exhaust temperature. It was noted that the excess air percentage should be maintained below 10% and stack exhaust temperature should keep to a minimum. Variation of first law and second law efficiency is represented in **Fig.2.1** and Fig **2.2** respectively. The obtained variation is about 0.2 – 0.25% for the temperature variation of 10˚C.

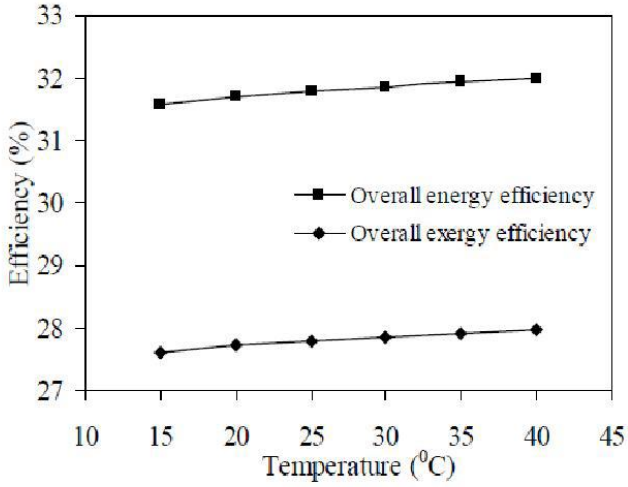


Figure 2.1 Variation of Efficiency with Inlet Air Temperature

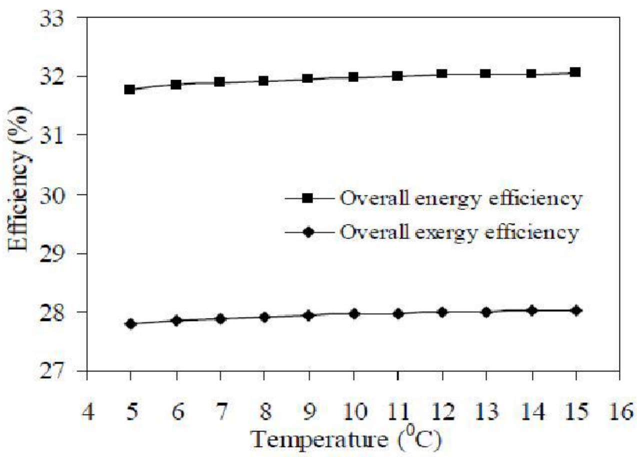


Figure 2.2 Variation of efficiency with Gain in Cooling Water Temperature across the Condenser.

At last they observed that the relative exergy losses in the combustor and evaporator are the highest compared with other parts of the plant. Finally, many recommendations have been suggested for improved plant performance.

3. Comparison between Regenerative, Reheat & Cogeneration Steam Plant on the basis of Turbine Inlet Temperature

The performances of turbines are affected due to the design of a particular operating condition such that steam inlet pressure, steam inlet temperature and turbine exhaust pressure/ exhaust vacuum. A variation in these parameters affects the steam consumption in the turbines and also the efficiency.

Gulab Chand Sahu, Manoj Sao, Abhishek Kumar Jain [6] studied for to recover the power output of the turbine, thermal efficiency and specific steam consumption in conventional steam power plants.

Three cycles' i.e. regenerative cycle, superheated cycle and cogeneration cycle or Combined Heat and Power (CHP) were consider to formulate the data and obtain a better result in steam turbine power plants. The effect of turbine inlet temperature on power output of the turbine, thermal efficiency and specific steam consumption for these cycles were analyzed.

Effect of Turbine Inlet Temperature on Power output of Turbine, Plant Thermal Efficiency and Specific steam consumption for Cogeneration cycle shown in Fig.3.1. Fig.3.2 and Fig.3.3 respectively.

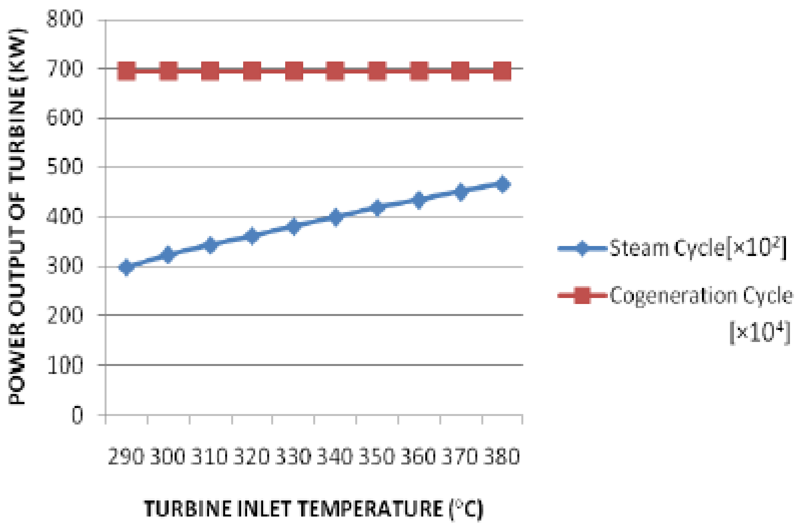


Figure 3.1Turbine inlet Temperature v/s Power output of turbine for Cogeneration cycle.

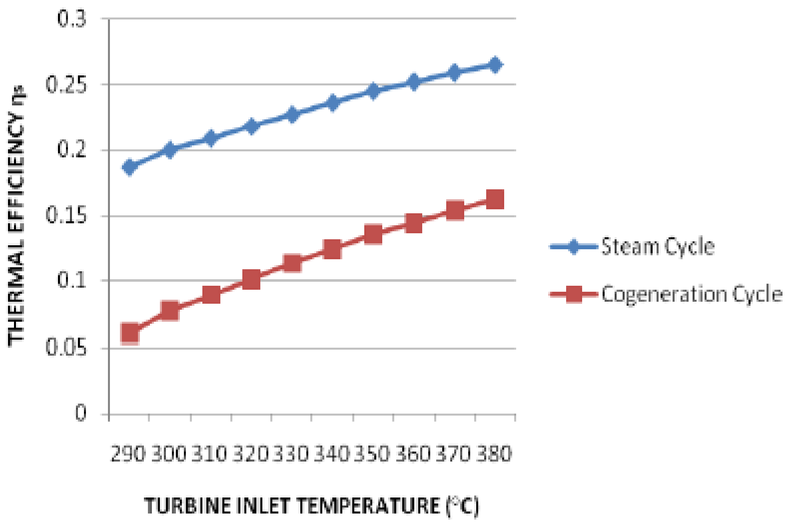


Figure 3.2Turbine inlet Temperature v/s Plant Thermal Efficiency for Cogeneration cycle.

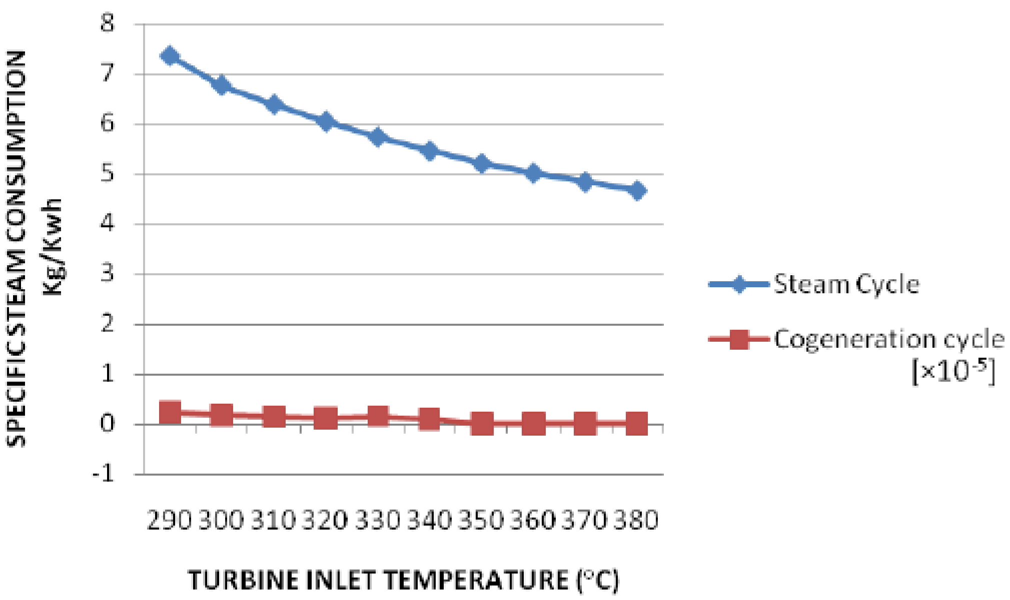


Figure 3.3Turbine inlet Temperature v/s Specific Steam Consumption for Cogeneration cycle.

The analysis of performance of a steam turbine power plant in terms of various cycles is as under.

- The cogeneration steam plant given more power output as compared to the regenerative steam plant and super heater steam plant with the increase in turbine inlet temperature.
- The regenerative steam plant and cogeneration steam plant having less thermal efficiency as compared to super heater steam plant with the rise in turbine inlet temperature.
- With the increase in turbine inlet temperature the specific steam consumption is least in cogeneration steam plant as compared to the regenerative steam plant and super heater steam plant.

The study showed that cogeneration steam power plants are more efficient as compared to conventional steam power plants as it conserve the quality of environment while enhancing the productivity, efficiency or utility of energy contribution. The turbine efficiency improves and the specific steam consumption is low.

4. Thermal Efficiency of Combined Cycle Power Plant

Power generation is most important for every country. This power is generated by some thermal cycles. But by using single cycle we cannot be attain complete power requirements and its efficiency also very low so that to fulfill this requirements, to combine two or more cycles in a single power plant then we can increase the efficiency of the power plant. Its increased efficiency is more than that of if the plant operated on single cycle.

R. Rajesh and Dr. P.S. Kishore [7] analyzed one practical combined cycle power plant using two different cycles and these two cycles are operated by means of different working mediums and Varying heat input to the gas turbine from 475 MW to 550 MW and maintaining compression ratio is 8.

These type of power plants called like combined cycle power plants. In combined cycle power plants above cycle is known as topping cycle and below cycle is known as bottoming cycle. The above cycle generally brayton cycle which uses air as a working medium. When the power generation was completed the exhaust gas will passes in to the waste heat recovery boiler. Another cycle also involved in bottoming cycle. This cycle works on the basis on rankine cycle. In which steam is used as working medium. The main component in bottoming cycle is waste heat recovery boiler. It will receive exhaust heat from the gas turbine and converts water in to steam. The steam used for generating power by expansion on steam turbine.

While analyzing practically combined cycle power plant, in practical conditions due to some losses it cannot be generates complete power. So they investigated why it is not give that much of power and the effect of various operating parameters such as maximum temperature and pressure of rankine cycle, gas turbine inlet temperature and pressure ratio of Brayton cycle on the net output work and thermal efficiency of the combine cycle power plant.

In this combined cycle power plant first operation is gas turbine operation in which when the combustion takes place in the combustion chamber it will expand in the gas turbine so that power will be obtained from this operation. Second operation is when exhaust gases expands in the gas turbine it enters into the waste heat recovery boiler so that the water which is presented in the boiler gets converted into the steam. This high pressure and temperature steam expand in the steam turbine so that the power will be obtained from the steam turbine.

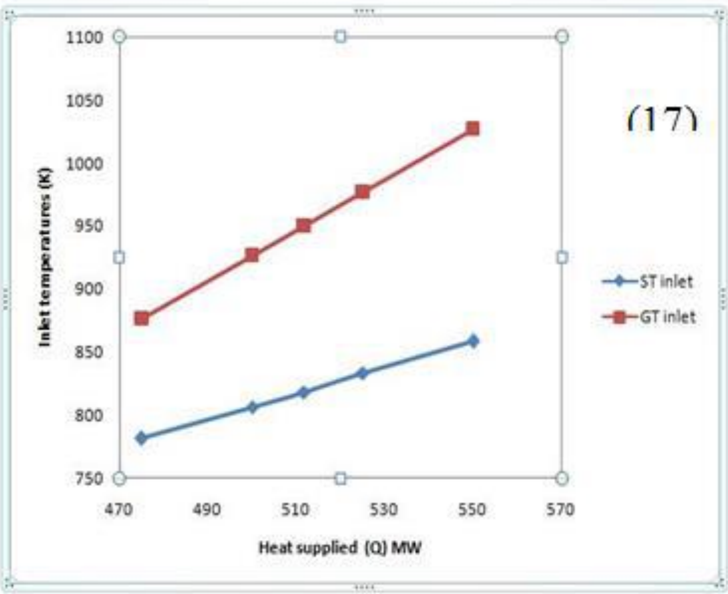


Figure 4.1 Variation of rate of inlet temperatures (K) with gas turbine heat supplied (Q)

Fig.4.1 shows the variation of inlet temperatures (K) with heat supplied in gas turbine (Q). Temperature increase is more in Brayton cycle (topping cycle) compared to Rankine cycle (bottoming cycle). As the heat supplied in gas turbine the inlet temperature of it increase and as well as steam turbine inlet temperature increases. At a particular point of heat supplied it was found that the inlet temperature of gas turbine is more than inlet temperature of steam turbine.

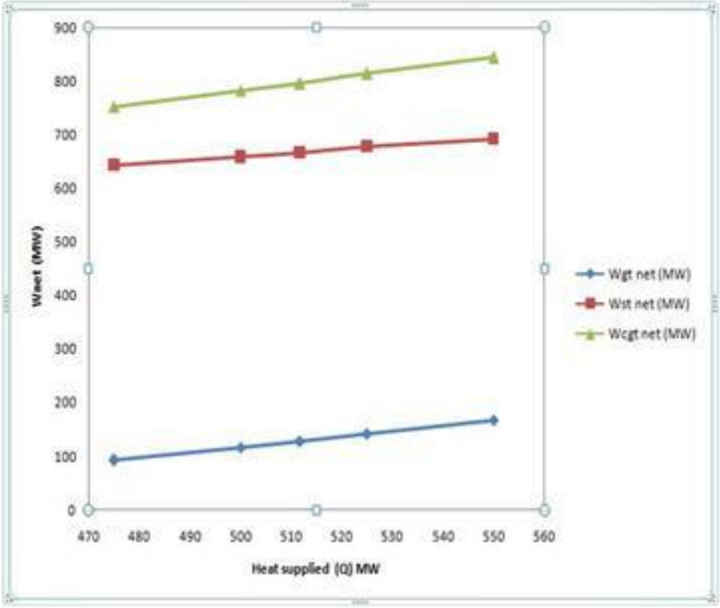


Figure 4.2 Variation of rate of Wnet with gas turbine heat supplied (Q)

Fig. 4.2 shows the variation of net work done with gas turbine heat supplied (Q). It is found that the work output of combined cycle power plant is more than that of steam power cycle and gas turbine cycle because combined cycle power plant work done is the sum of the work done of Rankine cycle power plant and gas turbine power plant. In gas turbine power plant it Consumes more work in compressor so it won't be able to produce more work output. In Rankine cycle, pump consumes very less work so that it produces somewhat high power output compared to the gas turbine.

Finally conclusions were summarized as,

1. Net work done by the gas turbine varies from 91.65 MW to 166.729 MW an increase of 29.36%. Net work done by the steam turbine varies from 643.606 MW to 692.848 MW an increase of 35.86%. Net work done by the combined cycle varies from 752.864 MW to 843.843.75 MW an increase of 39.64%.
2. The efficiency of the gas turbine varies from 19.86% to 44.86% an increase of 23.64%. The efficiency of the steam turbine varies from 26.179% to 51.62% an increase of 29.58%. The efficiency of the combined cycle varies from 30.624% to 55.91% an increase of 35.69%.
3. The input parameters of gas turbine and steam turbine such as inlet temperatures, input pressures increases, output parameters like work output of the gas turbine, steam turbine and combined cycle gas turbine are found to increase respectively.

5. Method to Improve Exergtic Efficiency of Power Plant Cycle by Heat Pipes

In thermodynamics, the exergy of a system is the maximum useful work possible during a process that brings the system into equilibrium with a heat reservoir, reaching maximum entropy. In the recent decades, exergy analysis has found increasingly widespread acceptance as a useful tool in the design, assessment, optimization and improvement of energy systems.

Exergetic analysis, based on second law of thermodynamics, takes in to account the energy quality. The energetic and exergetic analysis will provide a complete picture to improve the plant efficiency. Hence this exergy analysis can be generally applied to energy and other systems, it appears to be more powerful tool than energy analysis for power cycles because of the fact that it helps determine the true magnitudes of losses and their causes and locations, and improve the overall system and its components.

Dr. S.S. Rao [8] explored the possibility of reduction in exergy destruction by using Heat pipes in condenser and thus improving the exergtic efficiency a thermal power plant. The detailed explanation of exergy and exergy efficiency of different components of a thermal power plant was presented. Experimental setup and results of steam condenser loaded with heat pipes were presented.

It is proposed that the exergy reduction is possible in the condenser by successive cooling the dumped steam that the dumped steam is not directly cooled by cooling water. The heat energy from the steam is transferred to a third liquid which is a higher temperature than the cooling water and then the heat energy from this third liquid is transferred to the cooling water. The scheme can be depicted as below in **Fig 5.1.**

Figure 5.1Scheme of proposed heat transfer

It is known, that the exergy destruction depends on the temperatures of the fluid and environmental. Now, the steam is not exchanging the temperature directly with environment, hence there will be comparatively less exergy destruction in this proposed method.

By using Heat pipe it is clearly indicates that the heat pipe based condenser consistently transfer the dumped steam energy to the cooling fluid as shown in **Fig 5.2.**

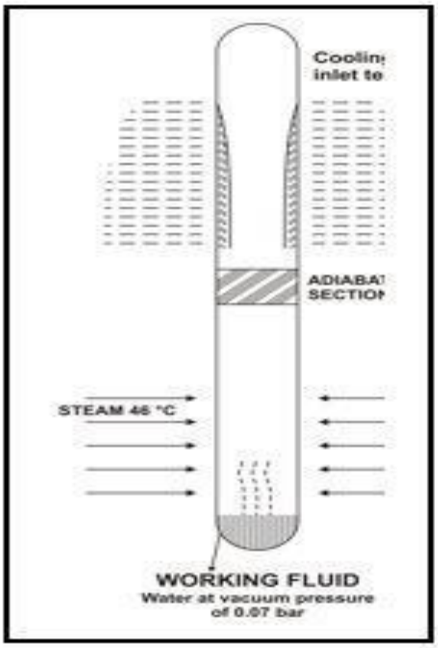


Figure 5.2 Designed Heat Pipe

Ten different trials were conducted and results were obtained also the performance of heat pipe based Condenser as shown in the **Fig.5.3.**

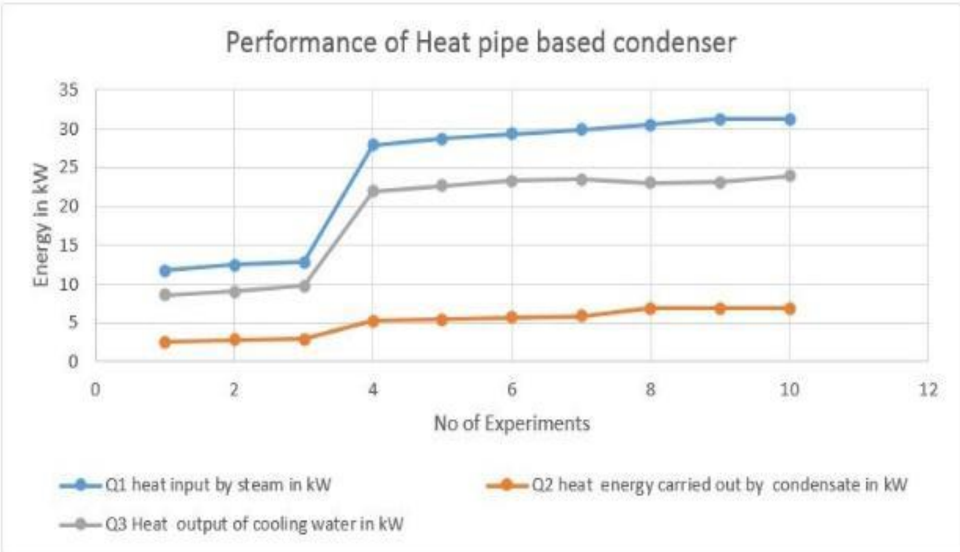


Figure 5.3 Performance of Condenser

Finally it is concluded that the Exergtic efficiency improvement in the Thermal power plant cycle is possible by reducing the exergy destruction in the condenser. This exergy destruction in the condenser is possible by successive cooling of the dumped steam in the condenser. This cooling method is possible by employing the heat pipes in place of conventional tubes in the condenser. Thus if successive cooling method is applied by employing heat pipes in the conventional condenser around 50 % of exergy destruction is possible. Hence the exgertic efficiency of the cycle improves.

After conducting experiments, it is clearly indicates that the heat pipe based condenser consistently transfer the dumped steam energy to the cooling fluid.

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