ISSN 2350 - 0328

International Journal of Advanced Research in Science, Engineering and Technology

Vol. 4, Issue 1, February 2017

Comparison Between Regenerative , Reheat & Cogeneration Steam Plant on the basis of Turbine Inlet Temperature

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ABSTRACT: Steam is a major energy consumer. Optimizing process operating conditions can considerably improve turbine water rate, which in turn will significantly reduce energy requirement. Various operating parameters influence condensing and back pressure turbine steam utilization and efficiency. The industrial sector is the largest energy consumer, accounting for about 30 % of total energy use. Fuel and energy prices are continuously increasing. With the present trend of energy prices and scarcity of hydrocarbon resources lowering energy requirement is a top priority. Energy preservation benefits depend on the adopting minor or major modifications and using the newest technology. 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. The present study was done 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 are considered to formulate the data and obtain a better result in steam turbine power plants.

KEYWORDS: Rankine Cycle, Regenerative Cycle, Super heater Cycle, Cogeneration Cycle, Turbine inlet Temperature.

I. INTRODUCTION

Power plants are where power is generated such as in the electricity generating stations and aircraft engines. Uses of turbine are the most important part of working these power plants. Steam has been a popular mode of conveying energy since the industrial revolution [1]. For generation of power Steam is uses and also it is used in process industries like sugar, paper, fertilizer, refineries, petrochemicals, chemical, food, synthetic fibre and textiles etc. The following characteristics of steam create it so popular and useful to the industry:

- Specific heat and latent heat of steam
- Better heat transfer coefficient
- Easy to control and allocate.
- Economical and still.

II. RANKINE CYCLE

The steam turbine power plant is totally based on the Rankine cycle which includes five processes: two isothermals, two isentropic and one constant pressure. Process 1-2: in this process the steam expanded isentropically from pressure p_1 to p_2 in the turbine. Process 2-3: the exhaust steam at constant pressure p_2 and temperature T_2 from the steam turbine is condensed in the condenser. Process 3-4: The water from the hot-well or the surge tank which is at low pressure is isentropically pumped into the boiler at high pressure p_1. Process 4-

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5: As the water enters the boiler, initially water is heated up to the saturation temperature or evaporation temperature T_1 known as sensible heating and in this process state point goes along curve 4-5. Heat supplied in this procedure is h_{f5}-h_{f4} and is known as sensible heat of water. Process 5-1: At constant pressure p_1 and temperature T_1, water is finally evaporated and converts to steam. Heat given in this process is equal to h_1-h_{f5} and known latent heat of vaporization [2].

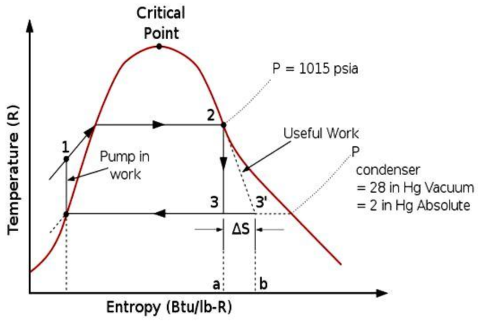

Figure 1: T-S Daigram for Rankine Cycle

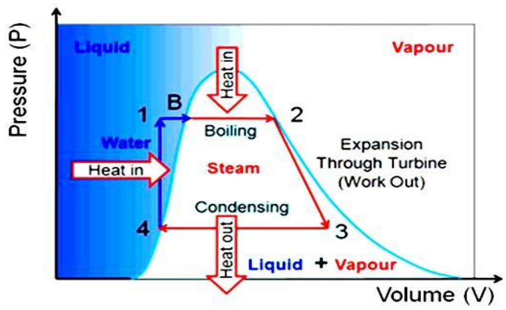

Figure 2: P-V Daigram for Rankine Cycle

III. REGENERATIVE CYCLE

The efficiency (thermal) of a steam power plant is increased by means of heat regeneration like gas-turbine plants. In regenerative cycle, the feed water is preheated by steam taken from some sections of the turbine, before it goes to the steam generator from the condenser. This process of exhausting steam from the turbine at certain point during its expansion and using it for heating the feed water supplied to the boiler is known as "Bleeding." Due to this process the boiler with hotter water while a small amount of work is lost by the turbine. Process 1-2: The steam is bled from the turbine and passed on to the heater. Process 1-3, which shows the isentropic expansion of remaining steam in the turbine from pressure p_1 to p_3. Process 3-4: At constant pressure p_3 and temperature T_3, the drain steam from the steam turbine is condensed in the condenser. Process 4-5: The feed water from condenser is pumped to heater. Process 5-6: Here in this heater (1-ms) kg of steam is heated. Process 2-6: Here in this heater ms kg of steam is to be condensed. Process 6-7: Water from the heater which is at low pressure is pumped into the boiler with high pressure. Process 7-1: At constant pressure p_1 & temperature T_1, the water is completely evaporated into steam.

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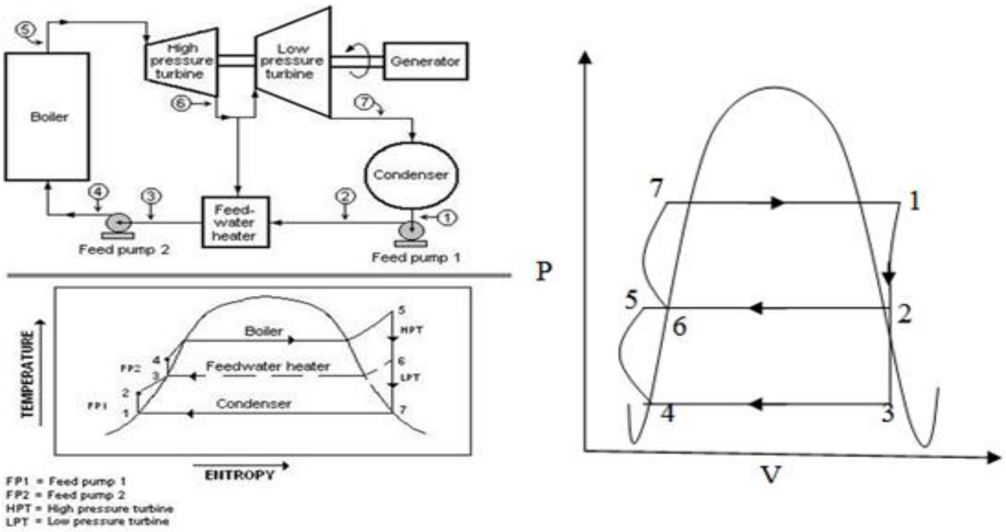

Figure 3: Plant Layout with T-S & P-V daigram of Regenerative Cycle

IV. SUPERHEATER CYCLE

It is a device which heats the steam produced by the boiler again, rising its thermal energy and decreasing the likelihood that it will condense inside the engine. Super heaters raise the efficiency of the steam turbine, and were widely adopted. The Steam which has been superheated is logically called as superheated steam. Superheated steam temperature is higher than boiling point of water. When saturated steam is heated at constant pressure, its temperature will also remain constant as the steam quality (think dryness) increases towards 100% dry saturated steam. Continued heat input will then produce superheated steam.

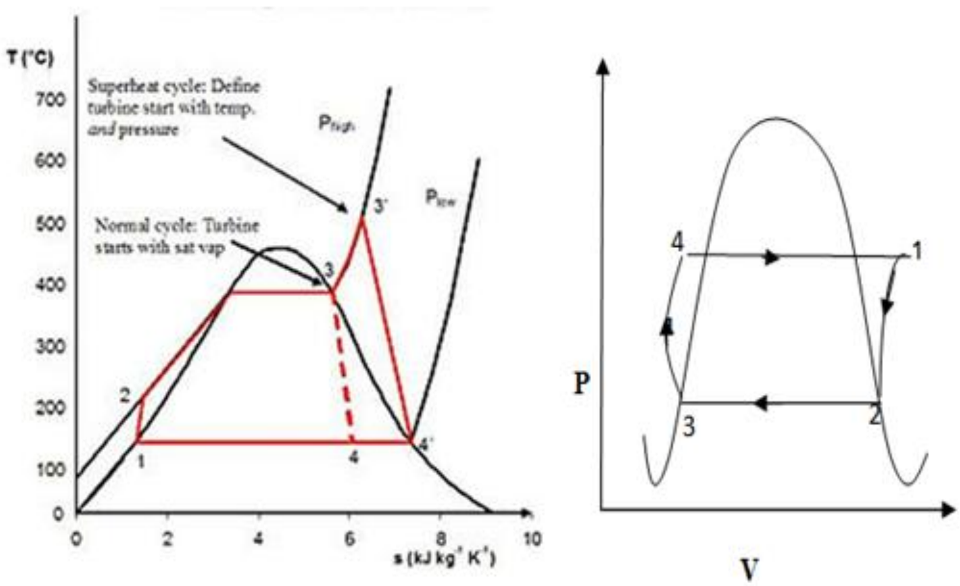

Figure 4: T-S & P-V Daigram for Superheater Cycle

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V. COGENERATION CYCLE

Cogeneration or Combined Heat and Power (CHP) is the sequential generation of two dissimilar forms of useful energy from a single primary energy source, typically mechanical energy and thermal energy. Mechanical energy may be used either, to drive an alternator for generating electricity, or rotating equipment such as motor, compressor, pump or fan for delivering a variety of services. Thermal energy may be used either for direct process applications or for indirectly generating steam, hot water and hot air for dryer or chilled water for process cooling. This cycle provides a wide range of technologies for application in various domains of economic activities. Overall efficiency of energy use in cogeneration mode can be up to 85% and above in some cases. Process 1-2: The steam is continuously taken out from the turbine and passed on to the process heater. Process 1-3, which shows the isentropic expansion of remaining steam in the turbine from pressure p_1 to p_3.

Process 3-4: At constant pressure p_3 and temperature T_3, the drain steam from the steam turbine is condensed in the condenser. Process 4-5: Water from the hot-well or the surge tank which is at low pressure is pumped into the boiler at high pressure. Here the pumping process 4-5 is isentropic. Process 2-6: Steam which could have been a waste is used as a process heat to produce electricity. Process 6-7: Water from the process heater which is at low pressure is pumped into the boiler at high pressure. Process 8-1: Here the water is totally evaporated into steam and this steam goes into the turbine.

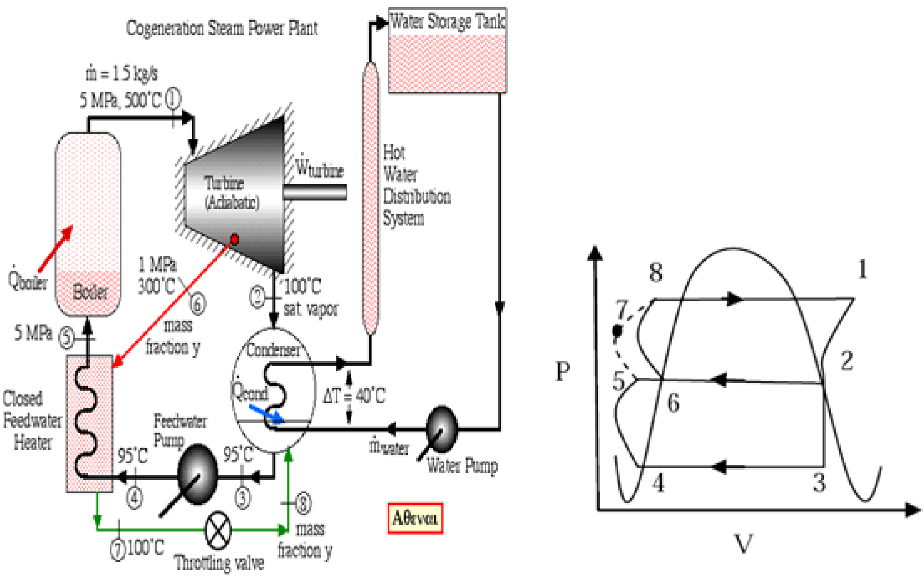

Figure 5: Plant Layout with P-V Daigram of Cogeneration Cycle

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Table 1: following data to be taken

At P_1 bar, the entrance enthalpy h_1 kJ/kg is taken. From Steam table	
At P_2 = 0.1 bar	At P_3 = 0.09 bar
h_{fg2} = 2392.8 kJ/kg	h_{f3} = 183.3 kJ/kg
h_{f2} = 191.8 KJ/Kg	
Dryness fraction of steam, x_2 = 0.9.	

VI. EQUATION

[i] The mass flow rate of steam, $m_s = \frac{Q_2}{h_2 - h_{f3}}$ in kg/hr

[ii] The power rate of turbine, $P = \frac{m_s(h_1 - h_2)}{3600}$ in kW

[iii] The thermal efficiency of the plant, $\eta = \frac{(h_1 - h_2)}{(h_1 - h_{f2})}$

[iv] The work done on the turbine, $W_T = (h_1 - h_2)$ in kJ/kg

[v] The work done on the pump, $W_P = V_{f(p2)} \times (P_1 - P_2) \times 100$ in kJ/kg

[vi] The net work done, $W_{net} = (W_T - W_P)$ in kJ/kg

[vii] Specific steam consumption, $SSC = \frac{3600}{W_{net}}$

[viii] Turbine exit enthalpy $h_2 = h_{f2} + x_2 \times h_{fg2}$ in kJ/kg

[ix] Heat lost by steam = heat gained by cooling water

$Q_2 = Cp\,(T_2 - T_1) \times mw$ in kJ/hr

VII. RESULTS AND DISCUSSION

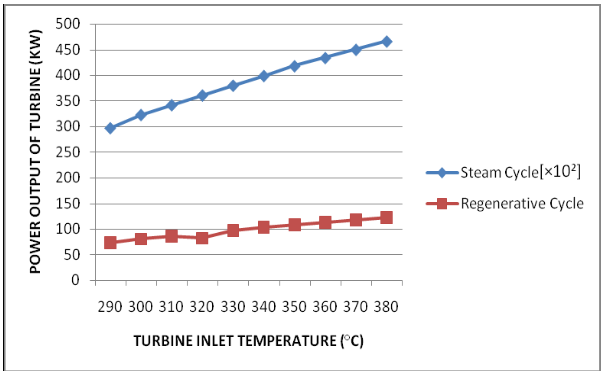

Figure 6: Power output Vs Inlet Temperature of turbine

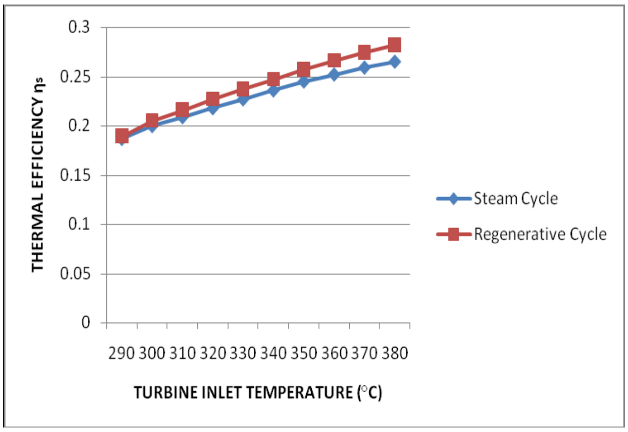

Figure 7: Thermal efficiency Vs Inlet Temp. of turbine

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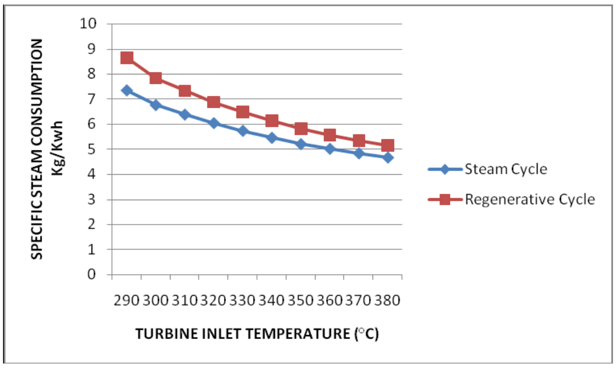

Figure 8: Sp. Steam Consumption Vs Inlet Temperature of turbine

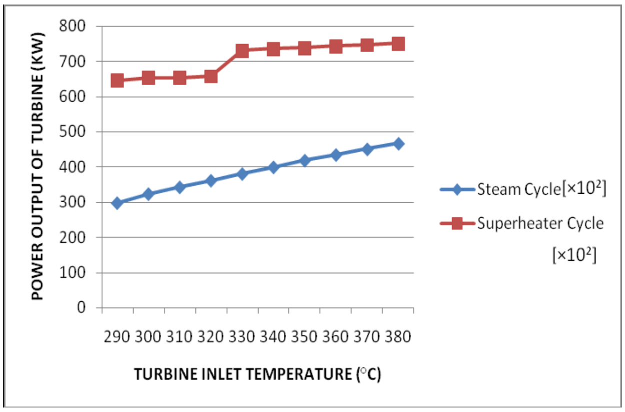

Figure 9: Power output Vs Inlet Temperature of turbine

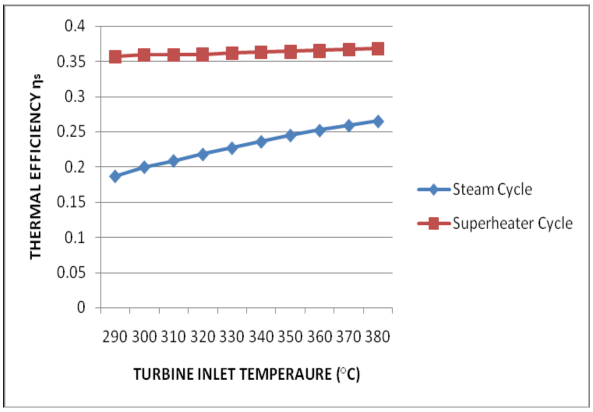

Figure 10: Power output Vs Inlet Temperature of turbine

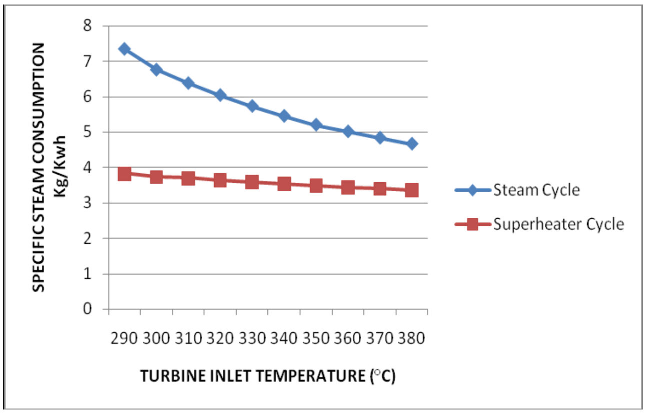

Figure 11: Sp. Steam Consumption Vs Inlet Temp.

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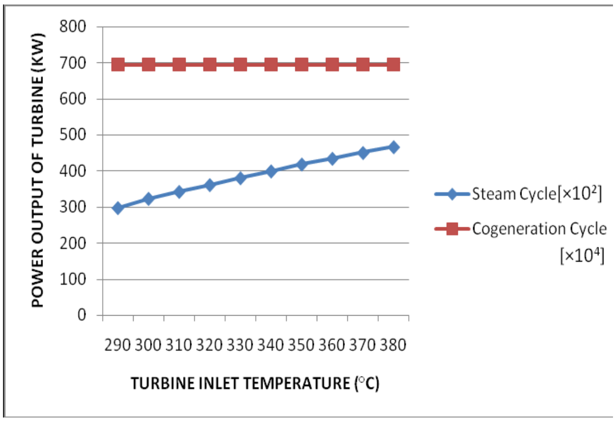

Figure 12: Power output Vs Inlet Temperature of turbine

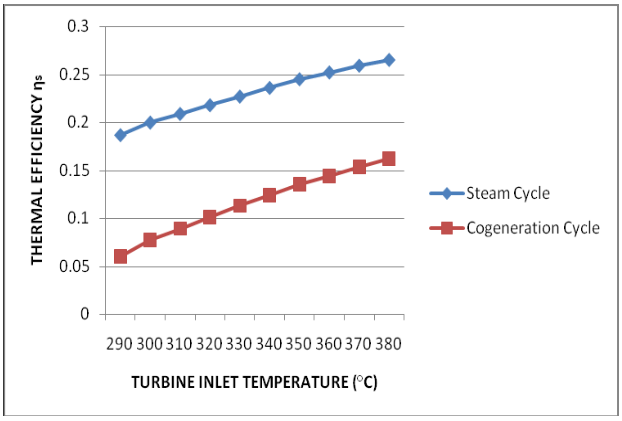

Figure 13: Thermal efficiency Vs Inlet Temperature

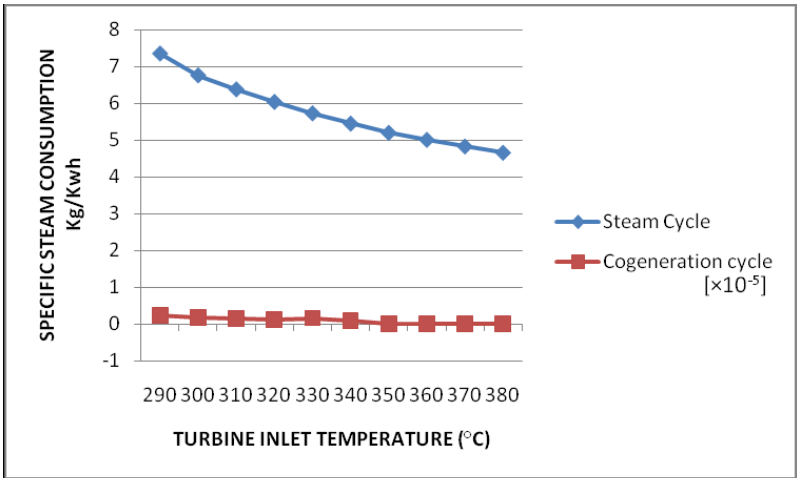

Figure 14: Sp. Steam Consumption Vs Inlet Temperature

Figure [6] shows the difference of the power output of the turbine with turbine inlet temperature. The raise in turbine inlet temperature means an increase in superheat at constant inlet steam pressure and condenser pressure provides a steady improvement in the power output of the turbine. Increasing the inlet steam temperature also decrease the wetness of the steam in the later stages of the turbine and increase the power output of the turbine. In steam cycle, the power output of the turbine raises uniformly with increase in turbine inlet steam temperature which thereby improves the quality of steam at the turbine exhaust. However, in regenerative cycle the power output of the turbine improves steadily with raise in turbine inlet temperature and

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
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is lower than simple steam cycle as some of the steam is bled from the turbine and brought back through the heater and fed to the boiler through pump.

Fig [7] represents the deviation of the thermal efficiency with recess temperature of turbine. The thermal efficiency will increase step by step with increase in recess steam temperature of turbine in steam cycle; therefore will increase the quality of steam at the turbine exhaust. In regenerative cycle, the thermal efficiency of the cycle will increase with the rise in turbine recess temperature and is more than the simple steam cycle as the supply water passing through the boiler is hotter and preheated by the heater. During this way heat addition to the boiler is inflated and reduces the wetness of steam thereby increasing the efficiency of the cycle. Also at 2900C, thermal efficiency of each the cycles are nearly same as the steam entering the turbine is not enough preheated to give an improved result.

Fig [8] represents the variation of specific steam consumption with inlet temperature of turbine. Reduces the wetness of the steam in the later stages of the turbine and also decreases specific steam consumption with increasing the inlet steam temperature. by lower temperature, enthalpy, work done by the turbine and turbine efficiency will be low, hence steam consumption for the necessary output will be higher. In other words, at higher steam inlet temperature, heat removal by the turbine will be higher and hence for the required output, steam consumption will be reduced. However, the specific steam consumption of regenerative cycle is higher than simple steam cycle as some of the steam is bled from the turbine and bring back through the heater and fed to the boiler during pumping. In doing so some work is lost in the turbine but feed water supplied to boiler is hotter which helps in getting better heat addition to the boiler and increases the specific steam consumption.

Fig [9] represents the variation of the power output of the turbine with inlet temperature of turbine. The increase in turbine inlet temperature means an increase in superheat at constant inlet steam pressure and condenser pressure gives a steady improvement in the turbine power output. With increasing the inlet temperature of steam also reduces the wetness of the steam in the later stages of the turbine and improves the turbine power output. In steam cycle, the power output of the turbine increasing uniform with increase in inlet steam temperature of turbine which thus increases the quality of steam at the turbine exhaust. A superheater is a machine used to exchange saturated steam or wet steam into dry steam used for power generation. The saturated steam is heated at constant pressure, its temperature remain constant as the steam quality increases to 100% dry saturated steam. Sustained heat input will generate superheated steam. Furthermore, with increase in superheat at constant pressure increases the mean temperature of heat addition and efficiency of cycle. As a result of which the quality of steam at turbine exhaust increases and performance of the turbine improves. as a result, in superheater cycle power output of the turbine increases with the increase in inlet temperature of turbine.

Fig [10] represents the variation of the thermal efficiency with inlet temperature of turbine. The increase in inlet temperature of turbine means an increase in superheat at constant inlet steam pressure and condenser pressure give an improvement with timely in the cycle thermal efficiency. With increase in the inlet temperature of steam also reduce the wetness of the steam in the later stages of the turbine and also improves the turbine internal efficiency. When the thermal efficiency of steam cycle is increases gradually, the inlet steam temperature is also increases the quality of steam at the turbine exhaust. A superheater is a device which is used to convert wet steam into dry steam used for power generation.

Fig [11] represents the variation of the specific steam consumption with turbine inlet temperature. At lower temperature, enthalpy, work done by the turbine, turbine efficiency will be low, hence steam consumption for the required output will be greater. In other words, at more steam inlet temperature, heat extraction by the turbine will be more and hence for the required output, steam consumption will decrease. However, the specific steam consumption of superheated cycle is lesser than simple steam cycle as the quantity of steam may be decreased by 10% to 15% for first 380C of superheat and somewhat less for the next 38˚C of superheat since additional heat has to be added in the boiler and consequently the capacity to do work in superheated steam is increased thereby decreasing the quantity of steam required for a given output of power.

Fig [12] represents the variation of the power output of the turbine with turbine inlet temperature. In steam cycle, the power output of the turbine raises uniformly with raise in turbine inlet steam temperature which thereby raises the quality of steam at the turbine exhaust. The power output of the turbine is much greater than simple steam cycle as in extraction cum condensing steam turbine as high pressure steam enters and passes out from the turbine chamber in stages, in cogeneration cycle. Mostly the amount of steam passes out to meet the process needs for process heating and balance amount of steam condenses in the surface condenser. For generating power the energy difference is used for generating power for which the power output of the turbine remains almost constant.

Fig [13] represents the variation of the thermal efficiency with turbine inlet temperature. In steam cycle, the thermal efficiency rises gradually with rise in turbine inlet steam temperature which thereby rises the quality of steam at the turbine exhaust., the thermal efficiency rises gradually in cogeneration cycle with rise in turbine inlet temperature but is lower than simple steam cycle as in removal cum condensing steam turbine as high pressure steam enters the turbine and passes out from the turbine chamber in stages. Mostly the amount of steam passes out to meet the process needs for process heating and balance amount of steam condenses in the surface condenser. For generating power is used the energy difference from the low grade waste heat from the process heater at low efficiency. At pressures significantly below that of 100% cogeneration facilities typically operate condensing power plants because of possible contamination of returned condensate from process steam and since much condensate is not recovered, meaning having to treat more make-up water.

Fig [14] shows the variation of the specific steam consumption with turbine inlet temperature. Increasing the inlet steam temperature also decrease the humidity of the steam in the later stages of the turbine and reduces specific steam consumption. Enthalpy, work done by the turbine and turbine efficiency will be low at lower temperature; hence steam consumption for the required output will be higher. In other words, at increased steam inlet temperature, heat extraction by the turbine will be increased and hence for the required output, steam consumption will be reduced. Since most of the quantity of steam passes out to meet the process needs for process heating and balance quantity of steam condenses in the surface condenser, the specific steam consumption of cogeneration cycle is much lower than simple steam cycle. The difference in energy is used for generating power or electricity. The steam thus extracted from the turbine is used for both heat and power. So the specific steam consumption is much lesser.

VIII. CONCLUSION

It can be expressed that the consideration in crucial the performance of a steam turbine power plant in terms of various cycles was analysed. The study of various parameter showed that turbine inlet temperature compete a really important role on the performance of a steam turbine power plant in terms of power output of the turbine, thermal efficiency and specific steam consumption. Thus, it can be brief into the following points:-

- 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

Consequently 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.

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