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EVALUATION OF THE IMPACT OF HIGH EXHAUST TEMPERATURE IN STEAM TURBINE OPERATION

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ABSTRACT

Steam turbine which operates due to dynamic action of the steam has a very high exhaust temperature. This work is done on the evaluation ofhigh exhaust temperature in steam turbine operation. Optimising process operating conditions can considerably improve the turbine water rate, which in turn will significantly reduce energy requirement. This work is furtherdesigned for particular operating conditions like steam inlet temperature and turbine exhaust pressure/exhaust vacuum, steam inlet pressure, which affects the performance of the turbines in a significant way. Variations in these parameters affect the steam consumption in the turbines and also the turbine efficiency. Improving the power output of the turbine, thermal efficiency and specific steam consumption in conventional steam power plants is inclusive. Four cycles, i.e; rankine cycle, regenerative cycle, superheat cycle and cogeneration cycle are considered to formulate the data and obtain a better result in steam turbine power.

Keywords: Rankine Cycle, Cogeneration Cycle, Regenerative Cycle, Superheat Cycle, Turbine inlet temperature, turbine exhaust temperature.

INTRODUCTION

Power is produced such as in the electricity generating stations and jet engines through power plants but steam has been a popular mode of conveying energy since the industrial revolution.Turbine is a rotary engine that converts the energy of a moving stream of water, steam, or gas into mechanical energy (Rajput, 2008). The basic element in a turbine is a wheel or rotor with addles, propellers, blades, or buckets arranged on its circumference in such a fashion that the moving fluid exerts a tangential force that turns the wheel and imparts energy to it. This mechanical energy is then transferred through a drive shaft to operate a machine, compressor, electric generator, or propeller. Turbines are classified as hydraulic, or water turbines, steam turbines, or gas turbines (Yadav, 2011). Today turbine-powered generators produce most of the world's electrical energy. This work is based on steam turbine.Steam is used for generating power and also used in process industries such as sugar, paper, fertilizer, refineries, petrochemicals, chemical, food, synthetic fibre and textiles. The following characteristics of steam make it so popular and useful to the industry:

- Highest specific heat and latent heat.
- Highest heat transfer coefficient.
- Easy to control and distribute.
- Cheap and inert.
- Ability to utilize high pressure and high temperature steam.
- High efficiency.
- High rotational speed.
- High capacity/weight ratio.
- Smooth, nearly vibration-free operation.
- No internal lubrication and Oil free exhaust steam.
- Can be built in small or very large units (up to 1200 MW).

MATERIALS AND METHOD

Bleeding is the process of draining steam from the turbine, at certain points during its expansion, and using this steam for heating the feed water supplied to the boiler. In this process a small quantity of steam, at certain sections of the turbine, is drained from the turbine and is then circulated around the feed water pipe leading from hot well to the boiler. The steam is thus condensed due to relatively cold water; the heat so lost by steam is transferred to the feed water. The condensed steam then finds its way to hot well. Bleeding plays important role in regenerative cycle.

- Rankine Cycle
- Regenerative Cycle
- Superheat Cycle
- Cogeneration Cycle

Rankine Cycle:

The steam turbine power plant is based on the rankine cycle which consists of five processes: two isothermals, two isentropic and one constant pressure.

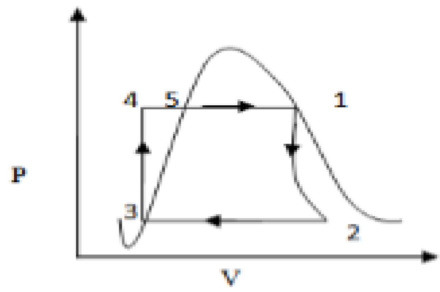

Figure 1: P-V diagram of rankine cycle

Process 1-2: This shows the isentropic expansion of steam in the turbine from pressure P_1 to P_2.

Process 2-3: At constant pressure P_2 and temperature T_2, the exhaust steam 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 pumped into the boiler at high pressure P_1. Here pumping process 3-4 is isentropic.

Process 4-5: As the water enters the boiler, water is first heated up to the saturation temperature or evaporation temperature T_1 called sensible heating and during this process the state point moves along curve 4-5. The heat supplied during this process is hf_5-hf_4 and is called sensible heat of water.

Process 5-1: At constant pressure P_1 and temperature T_1, water is completely evaporated into steam. The heat supplied in this process is equal to h_1-hf_5 and is called latent heat of vaporization.

Regenerative Cycle:

In this cycle, the feed water is preheated by means of steam taken from some sections of the turbine, before it enters the boilers from the condenser. This process of draining steam from the turbine at certain point during its expansion and using this steam for heating the feed water supplied to the boiler is known as “Bleeding.” The effect of this process is to supply the boiler with hotter water while a small amount of work is lost by the turbine.

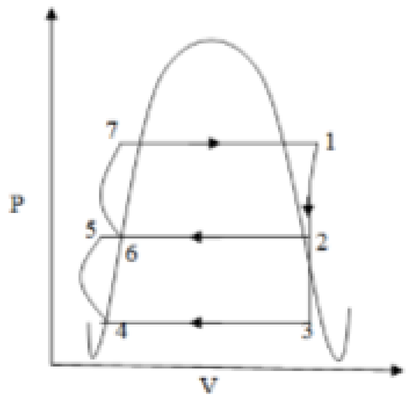

Figure 2: P-V diagram of regenerative cycle

Process 1-2: The steam is bled from the turbine and passed on to the heater.

Process 1-3: This 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 exhaust steam from the steam turbine is condensed in the condenser.

Process 4-5: Here the feed water from condenser is pumped to heater.

Process 5-6: In this heater (1-ms) kg of steam is heated.

Process 2-6: In this heater ms kg of steam condenses.

Process 6-7: The water from the heater which is at low pressure is pumped into the boiler at high pressure.

Process 7-1: At constant pressure P_1 and temperature T_1, water is completely evaporated into steam.

Super-heatercycle:

A super-heater is a device that heats the steam generated by the boiler again, increasing its thermal energy and decreasing the likelihood that it will condense inside the engine. Super-heaters increase the efficiency of the steam turbine, and were widely adopted. Steam which has been superheated is logically known as superheated steam. Superheated steam is steam at a temperature higher than boiling point of water. If 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 generate superheated steam.

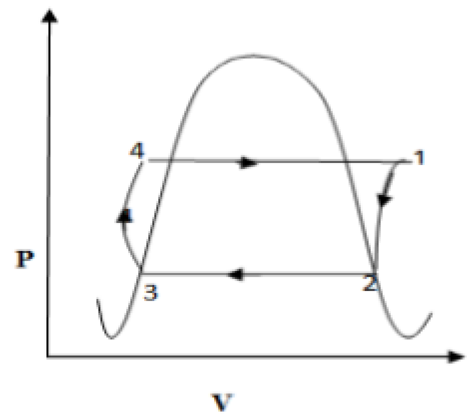

Figure 3: P-V diagram of super-heater cycle

Cogeneration Cycle:

Cogeneration or Combined Heat and Power (CHP) is defined as the sequential generation of two different forms of useful energy from a single primary energy source, typically mechanical energy and thermal energy. Mechanical energy may be used to drive an alternator for producing electricity, or rotating equipment such as motor, compressor, pump or fan for delivering various services. Thermal energy can be used either for direct process applications or for indirectly producing steam, hot water, hot air for dryer or chilled water for process cooling. Cogeneration provides a wide range of technologies for application in various domains of economic activities. The overall efficiency of energy use in cogeneration mode can be up to 85 percent and above in some cases.

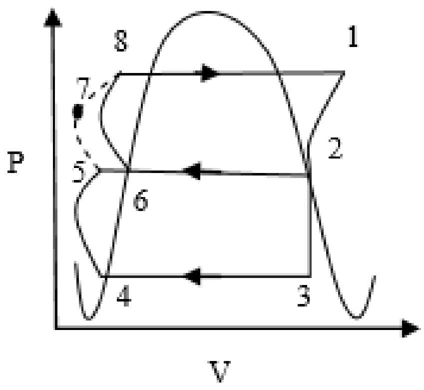

Figure 4: P-V diagram of cogeneration cycle

Process 1-2: The steam is continuously extracted from the turbine and passed on to the process heater.

Process 1-3: This 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 exhaust steam from the steam turbine is condensed in the condenser.

Process 4-5: The water from the hot-well or the surge tank which is at low pressure is pumped into the boiler at high pressure. Here pumping process 4-5 is isentropic.

Process 2-6: The steam which could have been a waste is utilized as a process heat to generate electricity.

Process 6-7: The water from the process heater which is at low pressure is pumped into the boiler at high pressure.

Process 8-1: Here water is completely evaporated into steam and this steam enters the turbine.

RESULTS AND DISCUSSION:

ANALYSIS:

At P_1 bar, the value of entrance enthalpy h_1 kJ/kg is taken.

At P_2bar,the value of hf_2 and hfg_2 are found out from steam table.

Given: dryness fraction of steam, x_2

Exit enthalpy from turbine $h_2 = hf_2 + x_2 \times hfg_2$ (kJ/kg)

Energy balance on condenser,

Heat lost by steam = heat gained by cooling water

$$Q_2 = C_p(T2 - T1) \times m_w \text{ (kJ/h)}$$

From steam table,

At P_3 bar, the value of $hf_3$is found

The mass flow rate of steam

$$m_s = Q_2 / (h_2 - hf_3) \text{ kg/h}$$

The power output of turbine,

$$P = m_s(h_1 - h_2)/3600 \text{ kw}$$

The thermal efficiency of the plant,

$$\eta_s = (h1 - h2)/(h1 - hf2)$$

The work done on the turbine,

$$W_T = h1 - h2 \text{ (kJ/kg)}$$

The work done on the pump,

$$W_p = V_f(p2) \times (P1 - P2) \times 100 \text{ (kJ/kg)}$$

The net work done,

$$Wnet = W_T - W_p \text{ (kJ/kg)}$$

Specific Steam Consumption, SSC = 3600/Wnet (kg/kWh)

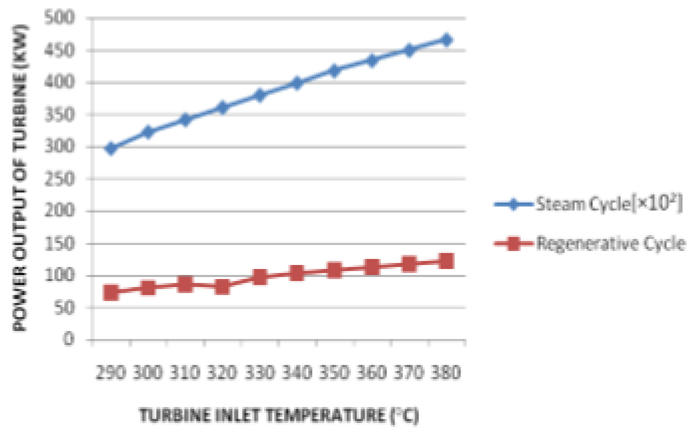

Figure 5: Power output vs TIT

Figure 5 shows the variation of the power output of the turbine with turbine inlet temperature. 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 power output of the turbine. Raising the inlet steam temperature also reduces the wetness of the steam in the later stages of the turbine and improves the power output of the turbine. In steam cycle, the power output of the turbine increases uniformly with increase in turbine inlet steam temperature which thereby increases the quality of steam at the turbine exhaust. However, in regenerative cycle the power output of the turbine increases steadily with increase in turbine inlet temperature and 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.

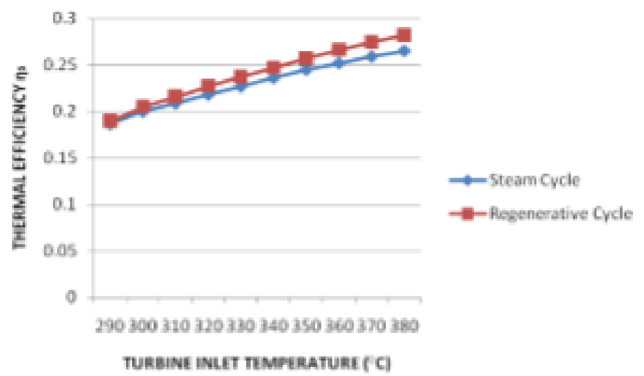

Figure 6: Thermal efficiency vs TIT

Figure 6 shows the variation of the thermal efficiency with turbine inlet temperature. In steam cycle, the thermal efficiency increases gradually with increase in turbine inlet steam temperature which thereby increases the quality of steam at the turbine exhaust. In regenerative cycle, the thermal efficiency of the cycle increases with the increase in turbine inlet temperature and is higher than the simple steam cycle as the feed water passing through the boiler is hotter and preheated by the heater. In this way heat addition to the boiler is increased and reduces the wetness of steam thereby increasing the efficiency of the cycle (Madu, 2018). Also at 2900^{O}C, thermal efficiency of both the cycles are nearly same as the steam entering the turbine is not enough preheated to give a better result.

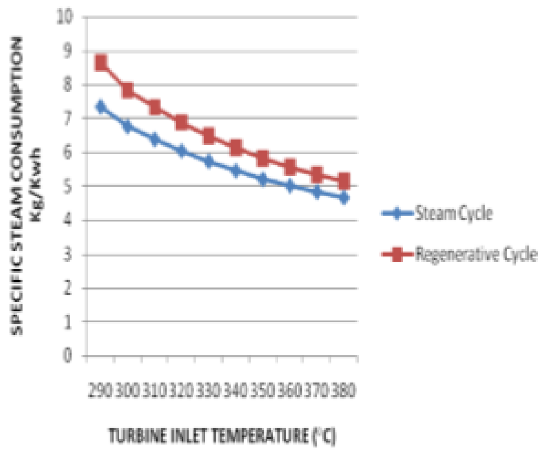

Figure 7: SSC vs TIT

Figure 7 shows the variation of specific steam consumption with turbine inlet temperature.Raising the inlet steam temperature also reduces the wetness of the steam in the later stages of the turbine and decreases specific steam consumption. At lower temperature, enthalpy will be low, work done by the turbine will be low, turbine efficiency will be low, and hence, steam consumption for the required output will be higher. In other words, at higher steam inlet temperature, heat extraction by the turbine will be higher and hence for the required output, steam consumption will reduce (Sharma, 2010). 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 brought back through the heater and fed to the boiler through pump. In doing so some work is lost in the turbine but feed-water supplied to boiler is hotter which helps in improving heat addition to the boiler and increases the specific steam consumption.

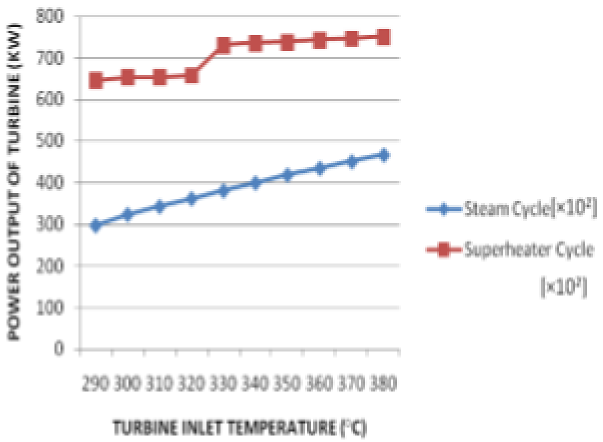

Figure 8: Power output vs TIT

Figure 8 shows the variation of the power output of the turbine with turbine inlet temperature. 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 power output of the turbine. Raising the inlet steam temperature also reduces the wetness of the steam in the later stages of the turbine and improves the power output of the turbine. In steam cycle, the power output of the turbine increases uniformly with increase in turbine inlet steam temperature which thereby increases the quality of steam at the turbine exhaust (Kapooria, Kumar and Kasana, 2008). Superheated steam is steam at a temperature higher than water's boiling point. If saturated steam is heated at constant pressure, its temperature will also remain constant as the steam quality increases towards 100% dry saturated steam. Continued heat input will then generate superheated steam. Moreover, with increase in superheat at constant pressure increases the mean temperature of heat addition and also the cycle efficiency. As a result of which the quality of steam at turbine exhaust increases and performance of the turbine improves. Therefore, in super heater cycle, power output of the turbine increases with the increase in turbine inlet temperature.

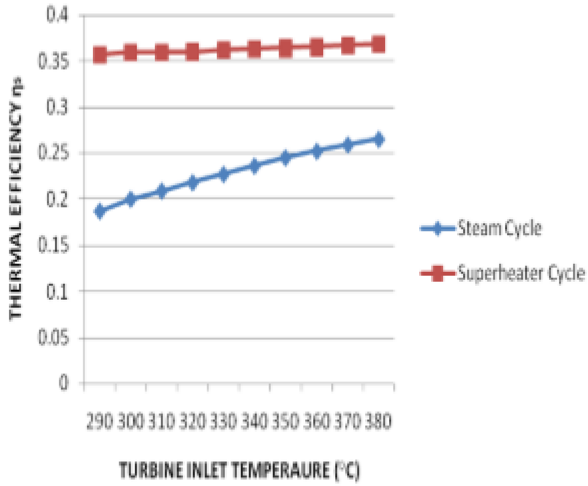

Figure 9: Thermal efficiency vs TIT

Figure 9 shows the variation of the thermal efficiency with turbine inlet temperature. 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 thermal efficiency of the cycle. Raising the inlet steam temperature also reduces the wetness of the steam in the later stages of the turbine and improves the turbine internal efficiency. In steam cycle, the thermal efficiency increases gradually with increase in turbine inlet steam temperature which thereby increases the quality of steam at the turbine exhaust. As a result of which the quality of steam at turbine exhaust increases and performance of the turbine improves. Therefore, in super-heater cycle the thermal efficiency almost remains same with the increase in turbine inlet temperature.

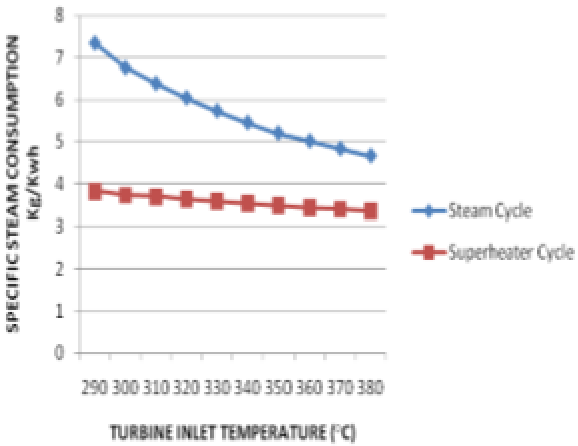

Figure 10: SSC vs TIT

Figure 10 shows the variation of the specific steam consumption with turbine inlet temperature. At lower temperature, enthalpy will be low, work done by the turbine will be low, turbine efficiency will be low, and hence steam consumption for the required output will be higher. In other words, at higher steam inlet temperature, heat extraction by the turbine will be higher and hence for the required output, steam consumption will reduce. However, the specific steam consumption of super-heater cycle is lower than simple steam cycle as the quantity of steam may be reduced by 10% to 15% for first 380^{O}C of superheat and somewhat less for the next 380^{O}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 reducing the quantity of steam required for a given output of power.

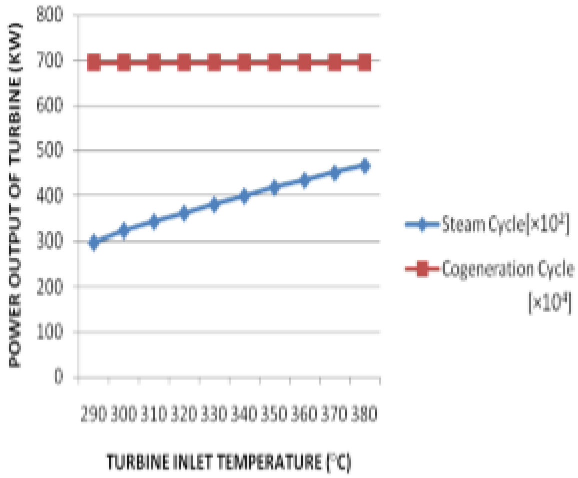

Figure 11: Power output vs TIT

Figure 11 shows the variation of the power output of the turbine with turbine inlet temperature. In steam cycle, the power output of the turbine increases uniformly with increase in turbine inlet steam temperature which thereby increases the quality of steam at the turbine exhaust. In cogeneration cycle, the power output of the turbine is much higher than simple steam cycle as in extraction cum condensing steam turbine as high pressure steam enters the turbine and passes out from the turbine chamber in stages. Mostly 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 energy difference is used for generating power for which the power output of the turbine remains almost constant.

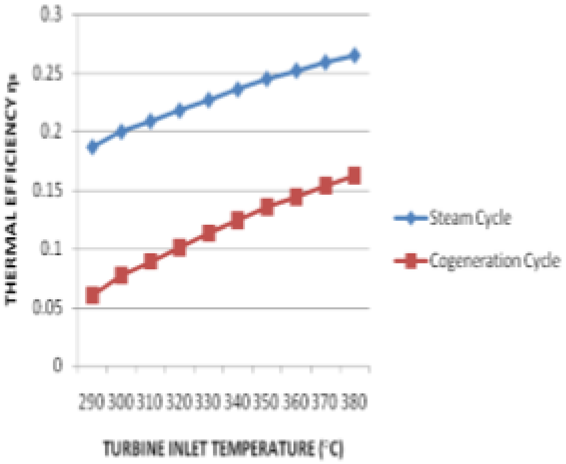

Figure 12: Thermal efficiency vs TIT

Figure 12 shows the variation of the thermal efficiency with turbine inlet temperature. In steam cycle, the thermal efficiency increases gradually with increase in turbine inlet steam temperature which thereby increases the quality of steam at the turbine exhaust. In cogeneration cycle, the thermal efficiency increases gradually with increase in turbine inlet temperature but is lower than simple steam cycle as in extraction cumcondensing steam turbine as high pressure steam enters the turbine and passes out from the turbine chamber in stages. Mostly, 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 energy difference is used for generating power from the low grade waste heat from the process heater at low efficiency. Cogeneration facilities typically operate at pressures significantly below that of 100% condensing power plants because of possible contamination of returned condensate from process steam and because much condensate is not recovered, meaning having to treat more make-up water.

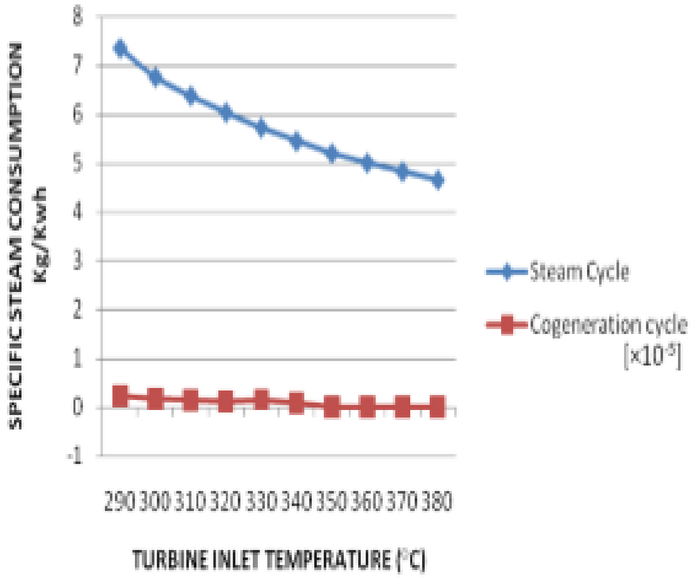

Figure 13: SSC vs TIT

Figure 13 shows the variation of the specific steam consumption with turbine inlet temperature. Raising the inlet steam temperature also reduces the wetness of the steam in the later stages of the turbine and decreases specific steam consumption. At lower temperature, enthalpy will be low, work done by the turbine will be low, turbine efficiency will be low, and hence, steam consumption for the required output will be higher. In other words, at higher steam inlet temperature, heat extraction by the turbine will be higher and hence for the required output, steam consumption will reduce. However the specific steam consumption of cogeneration cycle is much lower than simple steam cycle because 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 energy difference is used for generating power or electricity. Thus, the steam extracted from the turbine is used for both heat and power. So, the specific steam consumption is much lower.

CONCLUSION

In steam cycle, the power output of the turbine increases uniformly with increase in turbine inlet steam temperature which thereby increases the quality of steam at the turbine exhaust.Raising the inlet steam temperature also reduces the wetness of the steam in the later stages of the turbine and decreases specific steam consumption. The thermal efficiency increases gradually with increase in turbine inlet steam temperature which thereby increases the quality of steam at the turbine exhaust. At higher steam inlet temperature, heat extraction by the turbine will be higher and hence for the required output, steam consumption will reduce. However, the specific steam consumption of cogeneration cycle is much lower than simple steam cycle because 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 energy difference is used for generating power or electricity. Thus, the steam extracted from the turbine is used for both heat and power.

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