Thermodynamic Analysis of Triple Pressure Heat Recovery Steam Generator

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Abstract

Thermodynamic analysis of the triple pressure reheat combined cycle gas turbine with duct burner are presented and discussed in this paper .The overall performance of a combined cycle Gas turbine power plant is influenced by the ambient temperature and turbine inlet temperature. These parameters affect the overall thermal efficiency, power output .The ambient temperature increases the gas temperature and also the individual steam production rate also increased at each stage of the turbine. The exergy is used to evaluate maximum irreversibility of the process present in the cycle.
Keywords: exergy, energy, HRSG

I. INTRODUCTION

Heat Recovery Steam Generator (HRSG) is an interface between the gas cycle and the steam cycle in combined cycles. The classical approach to HRSG optimization is the “pinch-point” method, i.e. imposing the minimum temperature difference between the two agents.

The worldwide demand for combined cycle power plants is growing dramatically, with some experts forecasting explosive growth over the next decade. In its basic form, a gas turbine exhausting into a heat recovery steam generator (HRSG) that supplies steam to a steam turbine cycle is the most efficient system of generating electric electricity today. The last two decades with unit plant efficiencies of 30% to 35%, comparable to the state-of-the-art fossil-fired power stations. The below calculations give the information about the performance increased by installing the HRSG in combined cycle power plant.

A. Steam Power Plant

Power plants generate electrical power by using fuels like coal, oil or natural gas. A simple power plant consists of a boiler, turbine, condenser and a pump. Fuel, burned in the boiler and super heater, heats the water to generate steam. The steam is then heated to a superheated state in the super heater. This steam is used to rotate the turbine which powers the generator.

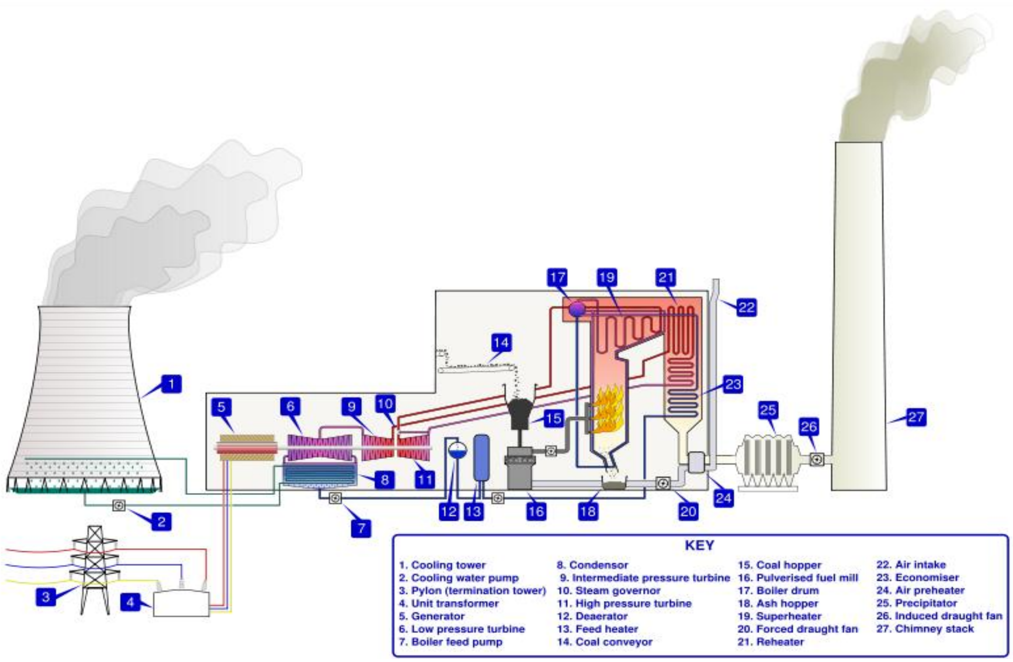

Fig. 1: Layout of Steam power plant

B. Brayton Cycle

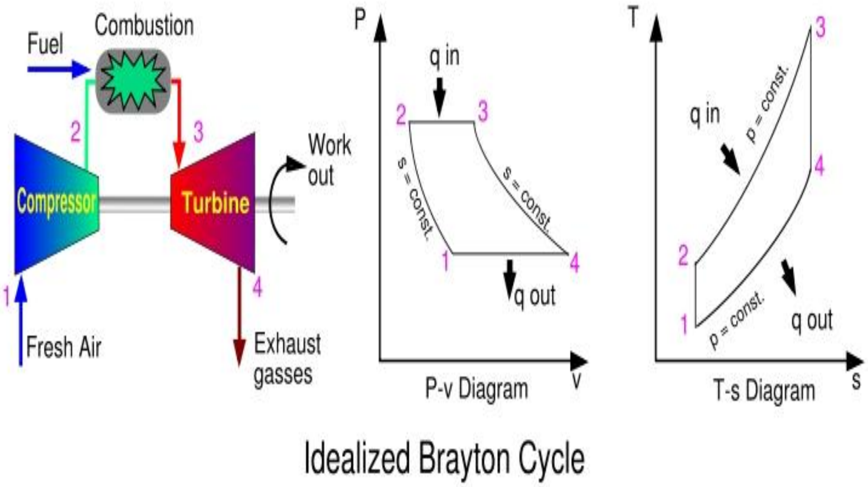

Fig. 2: Idealized Brayton cycle

Brayton cycle is the air standard cycle for the gas turbine power plant. Here air is first compressed reversibly and adiabatically, heat is added to it reversibly at constant pressure, air expands in the turbine reversibly and adiabatically, and heat is then rejected from the air reversibly at constant pressure to bring it to the initial state. The Brayton cycle consists of:

- Two Reversible Isobars
- Two Reversible Adiabatics

$$\eta = 1 - (Q1/Q2) \quad \text{(or)}$$
$$\eta brayton = 1 - 1/(rp)^\wedge(\gamma - 1/\gamma)$$

II. PLANT DESCRIPTION

Lanco Kondapalli Power Private Limited (LKPPL) has successfully set up India's first new generation 368 MW independent power plants at Kondapalli, IDA near Vijayawada in Andhra Pradesh in the year 2000. Stage-II expansion for gas fired 366 MW combined cycle in multi-shaft configuration (1GTG+1HRSG+1STG) was commissioned in 2010. LKPPL now adding stage-III by adding another two (2) combined cycle modules in the same configuration as that of stage-II. Nominal capacity of stage-III expansion shall be 750 MW and this shall be a dual fuel plant designed to operate in simple cycle and combined cycle mode.

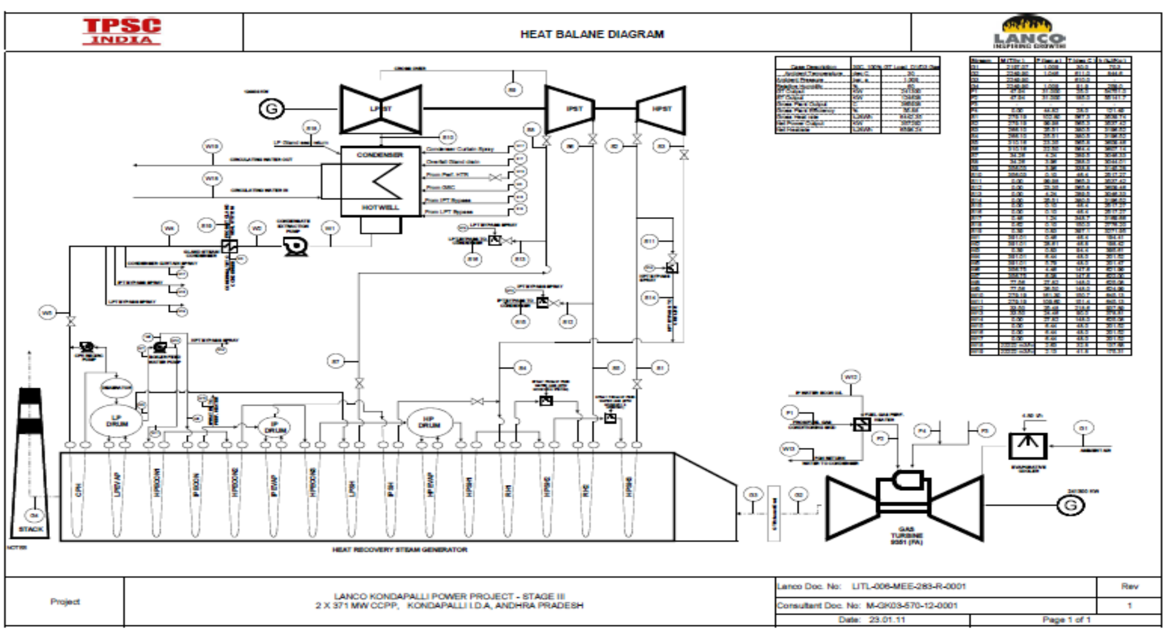

Fig. 3: Layout of lanco power plant with HRSG

The figure 3 shows different points and the necessary information of the particular point in order to say the quality of the steam/gas temperature, enthalpy and so on.

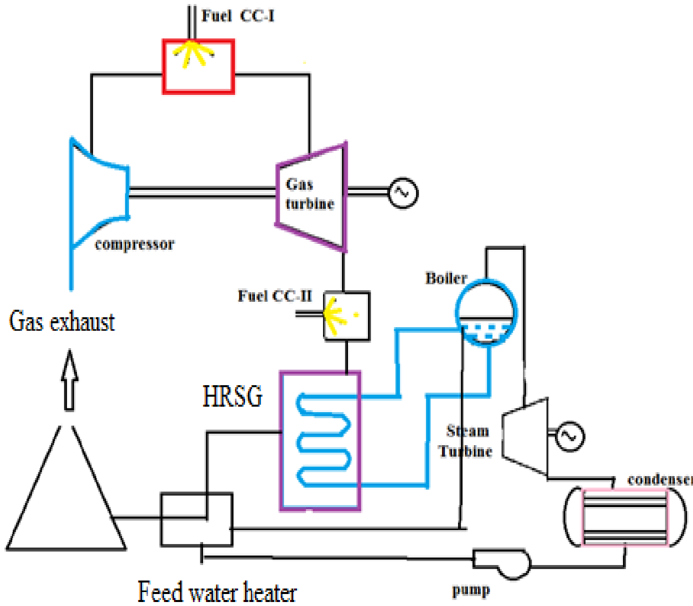

Fig. 4: layout diagram of combined cycle power plant with HRSG

The following tables gives the information regarding the operation of plant and the values of different points of the CC plant

A. Area Details of Each Section in HRSG

S.no	*Item description (HRSG)*	*AREA (m^2)*
1	*HP super heater*	*14754*
2	*IP super heater*	*3711.61*
3	*LP super heater*	*827.25*
4	*HP Evaporator*	*48610*
5	*IP Evaporator*	*24499*
6	*LP Evaporator*	*33404.5*
7	*HP Economizer*	*85366.7*
8	*IP Economizer*	*7423.3*
9	*CPH*	*58609.2*
10	*Reheater*	*16360.6*

B. Purposes and Scope

The purpose of this document is to briefly describe the Plant Control Philosophy for the Stage – III 2 x 371 MW Combined Cycle Gas Turbine Power Plant located in Kondapalli, near Vijayawada in Andhra Pradesh. The control philosophy is developed to enable the control & operation of the plant in a safe, effective, trouble free and reliable manner and to ensure the maximization of efficiency and the availability of the plant.

C. Heat Recovery Steam Generator (HRSG)

1) System Description:

Each HRSG is of Triple pressure, natural circulation, horizontal type mainly comprising of

1) HP/IP/LP boiler drums
2) Various Heat transfer sections
3) Drains and vents

Heat transfer sections are arranged in the direction of flow of exhaust gasses from the GT. In addition to the above HRSG also comprises, inlet Flue gas duct, outlet flue gas duct, main stack, and auxiliaries such as continuous and intermittent blow-down tanks etc.

The drum level to normal value. Attemperator is provided, utilizing feed water, to HP super heater sections and re-heater section. No attemperation Feed water to each drum goes via modulating level control to maintain is required for LP super heater.

III. PERFORMANCE ANALYSIS

The performance of the HRSG equipment is calculated and its parameters are listed below at various points in the HRSG equipment.

For ambient temperature $T_{amb}= 15^0C$

1) Heat content passed within the HRSG:

$$Q = m\, c_p\, (t_{in}-t_{out})$$

2) Heat developed within HP-Super heater:

$$Q = m\, c_p\, (t_{in}-t_{out})$$

3) Heat developed within IP-Super heater:

$$Q = m\, c_p\, (t_{in}-t_{out})$$

4) Heat developed within LP-Super heater:

$$Q = m\, c_p\, (t_{in}-t_{out})$$

5) Heat developed within the HP-Evaporator:

$$Q = m\, c_p\, (t_{in}-t_{out})$$

6) Heat developed within the IP-Evaporator:

$$Q = m\, c_p\, (t_{in}-t_{out})$$

7) Heat developed within the LP-Evaporator:

$$Q = m\, c_p\, (t_{in}-t_{out})$$

8) Heat developed within the HP-Economizer:

$$Q = m\, c_p\, (t_{in}-t_{out})$$

9) Heat developed within the IP-Economizer:

$$Q = m\, c_p\, (t_{in}-t_{out})$$

10) Heat developed within LP-Economizer:

$$Q = m\, c_p\, (t_{in}-t_{out})$$

11) Heat developed within Reheater:

$$Q = m\, c_p\, (t_{in}-t_{out})$$

S.n	*Item description*	*For 15˚C(KW)*	*For 30˚C(KW)*	*For 45˚C(KW)*
1	*H.P Super heater*	*79710.42*	*81733.45*	*82311.25*
2	*I.P Super heater*	*8076.191*	*7865.027*	*8257.544*
3	*L.P Super heater*	*6160.484*	*5851.862*	*5702.048*
4	*H.P Evaporator*	*7048.55*	*7507.522*	*6557.224*
5	*I.P Evaporator*	*523.0518*	*688.7846*	*725.8779*
6	*L.P Evaporator*	*3070.4*	*2967.31*	*3074.26*
7	*H.P Economizer*	*45927.35*	*45576.76*	*45168.08*
8	*I.P Economizer*	*6852.458*	*6356.626*	*5943.659*
9	*L.P Economizer*	*47599.63*	*43138.11*	*42995.21*
10	*Re-heater*	*66760.62*	*69320.6*	*68695.99*

(Performance data of HRSG and steam turbine (with respect to different ambient temperatures)

The following graphs show the various relationships with respect to the other parameter.

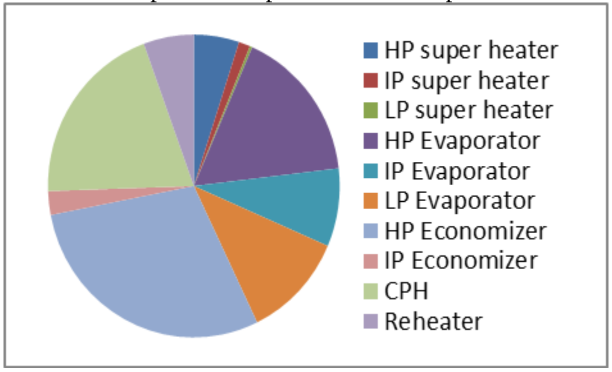

Fig. 5: Graph 1: Distribution of area of each component to that of total HRSG area

The above Graph gives the necessary information of the area of the HRSG with respect to all the components. The figure gives the idea that HP evaporator comprises more area to that of total area. The LP super heater having less surface area distribution to the total area in the HRSG equipment.

IV. ENERGY ANALYSIS

Energy extracted by flue gases is equal to energy utilized for total steam prepared in Triple pressure HRSG boiler. The energy balance equation is given by:
$m_{gas} c_p (T_{in}\text{-}T_{out}) = m_{hp} c_p (t_{sat,in}\text{-}t_{in}) + m_{hp}(h_{fg}) + m_{hp} c_p (t_{hp} - t_{sat}) + (m_{Ip} - m_{hp}) c_p (t_{sat}\text{-}t_{in}) + (m_{ip} - m_{hp}) h_{fg} + (m_{ip} - m_{hp}) c_p (t_{ip}\text{-} t_{sat\ ip}) + (m_{lp} - m_{ip}) c_p (t_{sat} - t_{in}) + (m_{lp} - m_{ip}) h_{fg} + (m_{lp} - m_{ip}) c_p (t_{lp} - t_{sat})$
Energy analysis carried out at the ambient temperature of 15˚C
Energy extracted from the gas =
663.61*1.14(869.8-364.3) = 382418.5 KW
Energy utilized by steam = $E_{HP\ steam} + E_{IP\ steam} + E_{LP\ steam}$

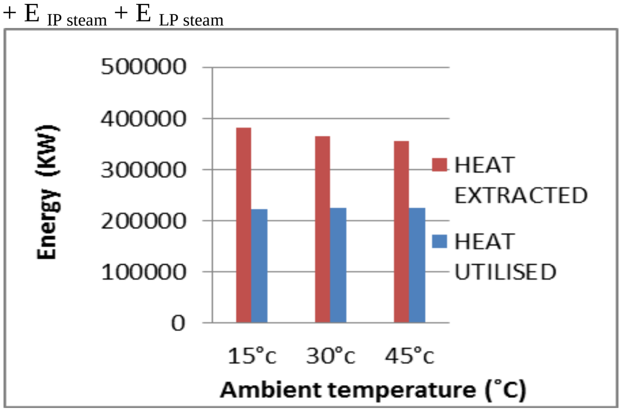

Fig. 6: Graph 2: Influence of ambient temperature on energy extraction and utilization

Graph presents the influence of ambient temperature and energy utilization and extraction, As the ambient temperature increases, heat energy i,e extracted energy goes on decreases where as the utilized heat energy of gases to that of steam production is more at 30˚C compared to other two cases.

V. EXERGY ANALYSIS

In order to evaluate the performance of a combined cycle, exergy analysis and energy analysis are used to establish the system model.
According to the exergy flow balance of the whole HRSG, considered as an open system, the exergy losses I_{HRSG} of the HRSG is given by:
$Ex_{g.\ in} - Ex_{g,\ out} = Ex_{w,\ in} + Ex_{s,\ in} - Ex_{s,\ out}$

In the above equation the terms $Ex_{w,\ in}$ and $Ex_{g,\ out}$ are zero because the inlet temperature of water is equal to the ambient temperature, and the exhaust gas from the HRSG cannot be used anymore, so the residual exergy of the gas can be considered zero too. The exergy losses related to the environment are not taken into consideration also. Assuming the exhaust gas pressure approaches atmospheric pressure, the exhaust gas exergy flow Ex_g can be expressed by:

$$Ex\ g,in = Cpg\ [(Tg - T0) - T0\ln\ (Tg/T\ 0)]\ mg$$

While the steam or the feed water exergy $Ex_{w,\ s}$ is calculated by:

$$Ex\ w,s = [(h - h0) - T0(s - s0)]\ m\ w,s$$

So exegy loss rate $Ex,_{HRSG} = I_{hrsg} / Ex_{g,\ in}$

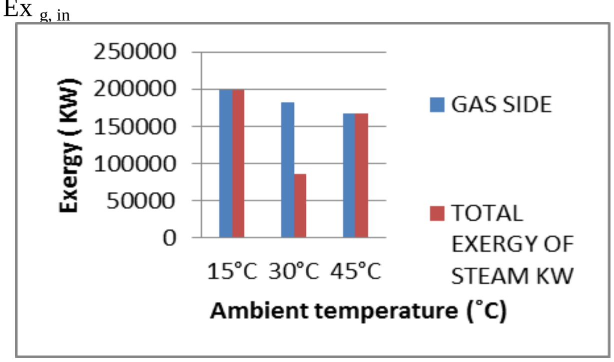

Fig. 7: Graph 3: Influence of total exergy to that of ambient temperature

Graph 3 presents influence of total exergy to that of ambient energy, where the gas side exergy is goes on decreasing with respect to the ambient temperature, the total exergy of steam production in case of 30°c is less compared to other.

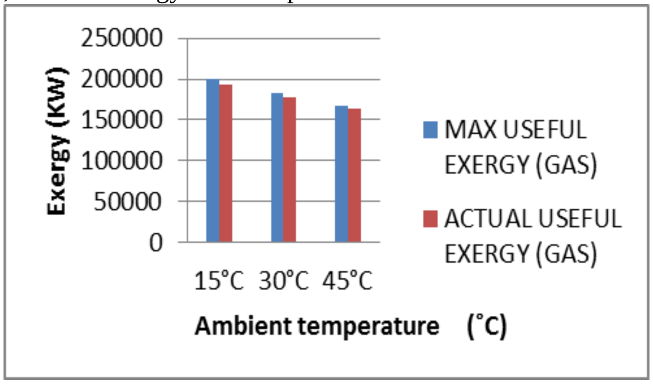

Fig. 8: Graph 4: Influence of ambient temperature for maximum and actual useful l exergy

Graph 4 presents the influence of ambient temperature for maximum and useful exergy production, where in all the cases the actual useful exergy is less compared to the maximum exergy. This gives the basics for the understand of the influence of ambient temperature.

VI. Combined Cycle Efficiency

The combined cycle efficiency of the power plant is given by the equation:

Efficiency of plant = $Wnet \,/\, mcp(t2 - t1) \; * 100$

$W_{net} = (W_{GT}+W_{ST})-(W_{COMP}+W_{PUMP})$

The plant efficiency at ambient temperature 15˚C
= 49.32%

The plant efficiency at ambient temperature 30˚C
= 48.34%

The plant efficiency at ambient temperature 45˚C
= 46.13%

A. Temperature Profile of the HRSG

The temperature profile of the HRSG describes the details of the temperature distribution in the component. This also helps to maintain the necessary temperature across the barrier. Therefore the temperature profile gives the importance of the HRSG temperature distribution at every point.

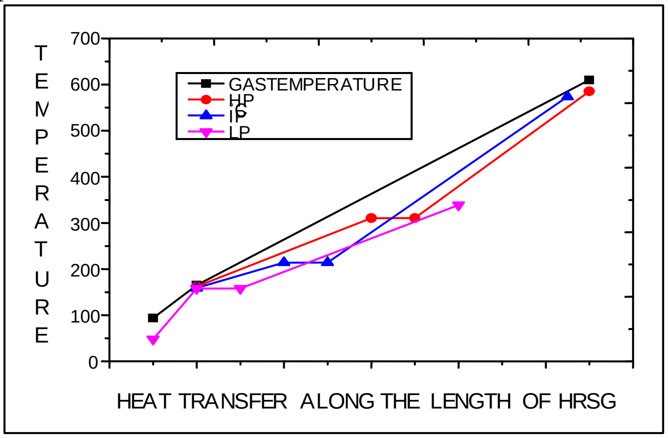

Fig. 9: Graph 5: Temperature profile of the HRSG equipment

The graph 5 represents the temperature profile of the HRSG equipment in the plant where the HP zone reaches up to 600˚C, IP region up to 585˚C, LP region up to 350˚C. In the figure black line represents the gas side temperature distribution, where the other represents the steam side temperature distribution. The temperature profile of the plant describes the starting point of each section of the HRSG equipment in terms of the temperature range.

VII. CONCLUSION

The ambient temperature showed more importance on the performance of HRSG equipment, as the ambient temperature increase the gas outlet temperature from gas turbine increases this helps to increase the heat content present in the flue gases. The more the ambient temperature the more the optimization of the HRSG thermodynamically and also yields to generate more amount of steam at high ambient temperature. This also observed in the plant details at different ambient temperatures point G3 in the table. The exhaust flue gas temperature is 596.8°C at 15°C ambient temperature, for 30°C ambient temperature 610°C temperature and for 45°C as ambient temperature the exhaust flue gas temperature is 619.8°C.This shows the ambient temperature importance on the performance of a CC power plant operation and its optimization and performance. The ambient temperature increases the gas temperature and also the individual steam production rate also increased at each stage of turbine.

The ambient temperature has its importance on the energy production, as the inlet temperature of the HRSG flue gas temperature increase the percentage of heat energy utilization increases because the inlet temperature increased, so the percentage of heat energy utilization also increased. The percentage of heat energy utilized at 15°C ambient temperature is 58.2%, for 30°C ambient temperature the percentage of heat energy utilized is 61% and for 45°C ambient temperature the percentage of heat energy utilized is 62.9%. This results the recommend of high HRSG inlet temperature.

The exergy analysis is done to evaluate the maximum irreversibility of the process present in the cycle. And the exergy is nothing but available energy so the available energy is maximum at 30°C compared to the other two cases. This helps to find out the minimization of Irreversibility at every case, in our thesis maximum at 30°C ambient temperature. The more the ambient temperature the less the Irreversibility because the expansion of gases is reached up to the reference temperature, this is the reason behind the increasing ambient temperature. Therefore the high ambient temperature is recommended in order to have less irreversibility and more available energy in the CC power plant. The combined cycle power plant is more at 15˚C ambient temperature and also the temperature profile diagram is shown in order to have the importance of the different regions with respect to the temperature.

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