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# Performance Analysis of a Heat Recovery Steam Generator

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***Abstract*** **: In view of the energy crisis, the heat recovery system at any stage is very much important is the field of conservation of energy.**

**The Heat Recovery steam Generator is one of the Critical components is the combined cycle (Gas Turbine cycle and Steam Power cycle) and is the most efficient energy conversation system in recent trends. Its function is to recover the waste heat present in the exhaust Gases of the Gas turbine cycle and to generate the steam to run a steam power cycle. This is an attempt to provide some information in this direction for the next Generation.**

**This work deals with to study the Performance and analysis of a Triple pressure Heat recovery steam generator in combined cycle power plant at different ambient conditions.**

**The results shows that the Increase of ambient temperature Increases the Exhaust outlet temperature from the gas turbine and thus increases the heat content present in the flue gases. so it is possible to generate more amount of steam at high ambient temperatures. It is observed that the percentage of heat utilization increases because the inlet temperature of heat recovery Steam Generator increases with increase of ambient temperature. It is noticed that the percentage of heat utilization increases as 58.2%, 61%, 62.9% for the ambient temperatures of 15$^0$c, 30$^0$c, 45$^0$c, respectively.**

***Key Words: Combined cycle , Gas Power Cycle, Heat Recovery Steam Generator, Steam power cycle, Ambient Temperature , Exhaust gas outlet temperature, Percentage of Heat Utilization.***

## 1.INTRODUCTION

Combined Cycle Power Plants are finding wider acceptance because it utilizes the Nature Gas which is available huge amount and it gives higher overall thermal efficiencies. It has Fast Start up capabilities and required least amount of cooling water for its functions. The Optimization of Heat Recovery Steam Generator is particularly important for design of combined plants to maximize the work to be developed in the vapour cycle. Multi Pressure steam generation in Heat recovery Steam generator of combined Power plant improves the performance of the plant. The Optimization of the Heat recovery Steam Generator is of particular interest in order to improve the efficiency of the heat recovery from the Gas turbine exhaust and to maximize the Power production in the Vapour cycle.

### *1.1.Present work :*

The Present work deals with to study the data collected from the Lanco Power Plant with Heat Recovery Steam Genarator.

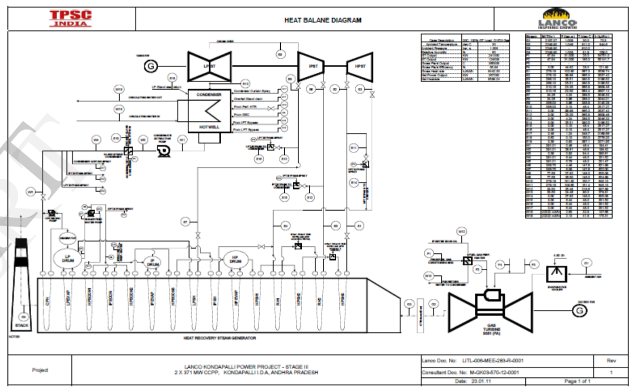


Fig. 1.1 Layout of Lanco Power Plant with HRSG (Courtesy-LANCO)

The Fig. 1.1 shows the different points and the necessary information of the particular point in order to give the quality of Steam/ Gas temperature, Enthalpy and so on.

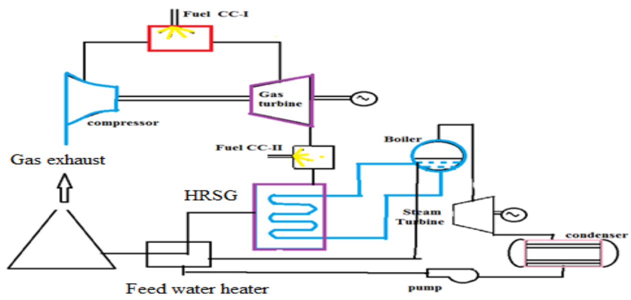


Fig.1.2. Line Diagram of combined power plant with HRSG.

The Fig 1.2 Shows the Line of Diagram of Combined Cycle Power plant with heat recovery Steam Generator.

The following Tables give the information regarding the operation of plant and values of different points of the combined cycle plant.

## 2. DESCRIPTION

### HEATRECOVERY STEAM GENERATOR (HRSG)

*About the Heat recovery Steam Generator*

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.

## 3. WORKING OF HRSG

The HRSG is designed to extract maximum recoverable heat from the exhaust gas of the gas turbine. For this purpose the exhaust gas flow from the gas turbine is arranged in a direction counter to the water/ steam circuit of HRSG. The exhaust gas

## 4. COLLECTED DATA FOR DIFFERENT OPERATING AMBIENT TEMPERATURE CONDITIONS.

Table 4.1: 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 |

From the gas turbine enters the HPSH 3, RH 2, and HPSH 2, RH 1, and HP super heater 1. From the Super heaters, the exhaust gases travel through the HP boiler evaporator ,IPSH ,LPSH , HP Economizer 3 , IP Evaporator , HP economizer 2 modules, IP Economizer, HP Economizer 1 , LP Evaporator and finally through the CPH (Condensate Pre heater) before exhausted to the atmosphere by the stack.

Case 1: For 15˚c as ambient temperature

Table 4.2: The table of values for 15°C :

| Case Description | 15°C, 100% GT load | |
|---|---|---|
| Ambient temperature | °c | 15 |
| Relative humidity | % | 60 |
| GT output | KW | 261000 |
| Ambient pressure | Bar | 1.009 |

| | | |
|---|---|---|
| ST output | KW | 131313 |
| Gross plant output | KW | 392313 |
| Gross plant efficiency | % | 56.45 |
| Gross heat rate | KJ/KWh | 6376.80 |
| Net power output | KW | 383470 |
| Net heat rate | KJ/KWh | 6523.85 |

| cc | M (T/hr) | P (bar, a) | T (°C) | h (KJ/Kg) |
|---|---|---|---|---|
| G1 | 2334.66 | 1.009 | 15.0 | 31.1 |
| G2 | 2389.00 | 1.054 | 597.8 | 798.2 |
| G3 | 2389.00 | - | 596.8 | - |
| G4 | 2389.00 | 1.009 | 91.3 | 232.7 |
| F1 | 50.87 | 31.000 | 25.0 | 54751.0 |
| F2 | 50.87 | 31.000 | 185.0 | 55141.7 |
| F3 | - | - | - | - |
| F4 | 0.00 | 44.82 | 16.0 | 71.44 |
| S1 | 283.17 | 103.40 | 555.9 | 3510.78 |
| S2 | 283.17 | 100.60 | 553.8 | 3508.46 |
| S3 | 270.08 | 25.90 | 371.9 | 3176.58 |
| S4 | 270.08 | 25.90 | 371.9 | 3176.58 |
| S5 | 317.69 | 23.72 | 554.3 | 3583.61 |
| S6 | 317.69 | 22.86 | 552.9 | 3581.29 |
| S7 | 36.00 | 4.34 | 289.4 | 3045.85 |
| S8 | 36.00 | 4.03 | 287.9 | 3043.52 |
| S9 | 365.31 | 4.03 | 330.3 | 3127.87 |
| S10 | 365.31 | 0.07 | 40.0 | 2449.10 |

| | | | | |
|---|---|---|---|---|
| S11 | 0.00 | 100.60 | 553.8 | 3508.46 |
| S12 | 0.00 | 23.72 | 554.3 | 3583.61 |
| S13 | 0.00 | 4.34 | 289.4 | 3045.85 |
| S14 | 0.00 | 25.90 | 371.9 | 3176.58 |
| S15 | 0.00 | 0.07 | 40.0 | 2449.10 |
| S16 | 0.00 | 0.07 | 40.0 | 2449.10 |
| S17 | 0.46 | 1.24 | 339.5 | 3151.05 |
| S18 | 0.62 | 0.10 | 150.0 | 2776.20 |
| S19 | 0.39 | 0.83 | 387.1 | 3250.29 |
| W1 | 401.85 | 0.43 | 40.0 | 167.39 |
| W2 | 401.85 | 28.49 | 40.3 | 171.34 |
| W3 | 0.39 | 0.83 | 94.4 | 395.61 |
| W4 | 401.85 | 6.93 | 41.5 | 174.41 |
| W5 | 401.85 | 6.24 | 41.5 | 174.35 |
| W6 | 365.85 | 4.57 | 148.5 | 625.94 |
| W7 | 365.85 | 6.19 | 148.5 | 625.88 |
| W8 | 82.68 | 28.38 | 148.9 | 628.98 |
| W9 | 82.68 | 27.03 | 148.9 | 628.90 |
| W10 | 283.17 | 160.40 | 151.6 | 648.87 |
| W11 | 283.17 | 110.30 | 152.3 | 648.87 |
| W12 | 35.07 | 25.99 | 220.3 | 945.62 |
| W13 | 35.07 | 24.95 | 90.0 | 378.85 |
| W14 | 0.00 | 28.38 | 148.9 | 628.98 |
| W15 | 0.00 | 6.93 | 41.5 | 174.41 |
| W16 | 0.00 | 6.93 | 41.5 | 174.41 |
| W17 | 0.00 | 6.93 | 41.5 | 174.41 |
| W18 | 22222m3/hr | 2.63 | 25.86 | 103.67 |
| W19 | 22222m3/hr | 2.13 | 34.98 | 146.66 |

Case 2: For 30°c as ambient temperature.

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

The following tables gives the information regarding the operation of plant and the values of different points of the Combined cycle plant.

| Case Description | 30°C, 100% GT load | |
|---|---|---|
| Ambient temperature | °c | 30 |
| Relative humidity | % | 60 |
| GT output | KW | 241300 |
| Ambient pressure | Bar | 1.009 |
| ST output | KW | 124638 |
| Gross plant output | KW | 365938 |
| Gross plant efficiency | % | 55.88 |
| Gross heat rate | KJ/KWh | 6442.35 |
| Net power output | KW | 357292 |
| Net heat rate | KJ/KWh | 6598.24 |

| Stream | M (T/hr) | P (bar, a) | T (°C) | h (KJ/Kg) |
|---|---|---|---|---|
| G1 | 2083.55 | 1.009 | 45.0 | 137.3 |
| G2 | 2135.20 | 1.040 | 620.8 | 888.1 |
| G3 | 2135.20 | - | 619.8 | - |
| G4 | 2135.20 | 1.009 | 93.9 | 287.6 |
| F1 | 45.55 | 31.000 | 25.0 | 54751.0 |
| F2 | 45.55 | 31.00 | 185.0 | 55141.7 |
| F3 | - | - | - | - |
| F4 | 0.00 | 44.82 | 42.0 | 179.84 |
| S1 | 273.37 | 101.00 | 572.0 | 3552.94 |
| S2 | 273.37 | 98.22 | 570.0 | 3550.62 |
| S3 | 260.28 | 25.10 | 385.7 | 3208.69 |
| S4 | 260.28 | 25.10 | 385.7 | 3208.69 |
| S5 | 304.82 | 22.98 | 567.4 | 3613.38 |
| S6 | 304.82 | 22.15 | 566.0 | 3611.05 |
| S7 | 33.70 | 4.23 | 287.9 | 3043.02 |
| S8 | 33.70 | 3.90 | 286.3 | 3040.70 |
| S9 | 350.14 | 3.90 | 340.1 | 3148.08 |
| S10 | 350.14 | 0.16 | 57.3 | 2609.38 |
| S11 | 0.00 | 98.22 | 570.0 | 3550.62 |
| S12 | 0.00 | 22.98 | 567.4 | 3613.38 |
| S13 | 0.00 | 4.23 | 287.9 | 3043.02 |
| S14 | 0.00 | 25.10 | 385.7 | 3208.69 |
| S15 | 0.00 | 0.16 | 57.3 | 2609.38 |
| S16 | 0.00 | 0.16 | 57.3 | 2609.38 |
| S17 | 0.46 | 1.24 | 352.3 | 3176.92 |
| S18 | 0.62 | 0.10 | 150.0 | 2776.20 |
| S19 | 0.39 | 0.83 | 401.8 | 3282.19 |
| W1 | 383.73 | 0.52 | 54.8 | 229.51 |
| W2 | 383.73 | 28.65 | 55.2 | 233.55 |
| W3 | 0.39 | 0.83 | 94.4 | 395.61 |
| W4 | 383.73 | 6.05 | 56.4 | 236.59 |
| W5 | 383.73 | 5.44 | 56.4 | 236.54 |
| W6 | 350.03 | 4.44 | 147.4 | 621.22 |
| W7 | 350.03 | 6.06 | 147.4 | 621.14 |
| W8 | 73.55 | 27.30 | 147.9 | 624.61 |
| W9 | 73.55 | 26.00 | 147.9 | 624.53 |
| W10 | 276.48 | 161.90 | 150.5 | 644.49 |
| W11 | 276.48 | 107.50 | 151.3 | 644.49 |
| W12 | 32.02 | 25.00 | 217.5 | 932.82 |
| W13 | 32.12 | 24.00 | 90.0 | 378.77 |
| W14 | 0.00 | 27.30 | 147.9 | 624.61 |
| W15 | 0.00 | 6.05 | 56.4 | 236.59 |
| W16 | 0.00 | 6.05 | 56.4 | 236.59 |
| W17 | 0.00 | 6.05 | 56.4 | 236.59 |
| W18 | 22222$m^3$/hr | 2.63 | 41.49 | 173.99 |
| W19 | 22222$m^3$/hr | 2.13 | 50.55 | 211.84 |

Case 3: For 45°C as ambient temperature.

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

The following tables gives the information regarding the operation of plant and the values of different points of the Combined cycle plant.

Table 4.6 : Table of values for 45°C are:

| Case Description | 45°C, 100% GT load | Case Description |
|---|---|---|
| Ambient temperature | °C | Ambient temperature |
| Relative humidity | % | Relative humidity |
| GT output | KW | GT output |
| Ambient pressure | Bar | Ambient pressure |
| ST output | KW | ST output |
| Gross plant output | KW | Gross plant output |
| Gross plant efficiency | % | Gross plant efficiency |
| Gross heat rate | KJ/KWh | Gross heat rate |
| Net power output | KW | Net power output |
| Net heat rate | KJ/KWh | Net heat rate |

Table 4.7: Table of values for the different points in HRSG

| Stream | M (T/hr) | P (bar, a) | T (°C) | h (KJ/Kg) |
|---|---|---|---|---|
| G1 | 2083.55 | 1.009 | 45.0 | 137.3 |
| G2 | 2135.20 | 1.040 | 620.8 | 888.1 |
| G3 | 2135.20 | - | 619.8 | - |
| G4 | 2135.20 | 1.009 | 93.9 | 287.6 |
| F1 | 45.55 | 31.000 | 25.0 | 54751.0 |
| F2 | 45.55 | 31.00 | 185.0 | 55141.7 |
| F3 | - | - | - | - |
| F4 | 0.00 | 44.82 | 42.0 | 179.84 |
| S1 | 273.37 | 101.00 | 572.0 | 3552.94 |
| S2 | 273.37 | 98.22 | 570.0 | 3550.62 |
| S3 | 260.28 | 25.10 | 385.7 | 3208.69 |
| S4 | 260.28 | 25.10 | 385.7 | 3208.69 |
| S5 | 304.82 | 22.98 | 567.4 | 3613.38 |
| S6 | 304.82 | 22.15 | 566.0 | 3611.05 |
| S7 | 33.70 | 4.23 | 287.9 | 3043.02 |
| S8 | 33.70 | 3.90 | 286.3 | 3040.70 |
| S9 | 350.14 | 3.90 | 340.1 | 3148.08 |
| S10 | 350.14 | 0.16 | 57.3 | 2609.38 |
| S11 | 0.00 | 98.22 | 570.0 | 3550.62 |
| S12 | 0.00 | 22.98 | 567.4 | 3613.38 |
| S13 | 0.00 | 4.23 | 287.9 | 3043.02 |
| S14 | 0.00 | 25.10 | 385.7 | 3208.69 |
| S15 | 0.00 | 0.16 | 57.3 | 2609.38 |
| S16 | 0.00 | 0.16 | 57.3 | 2609.38 |
| S17 | 0.46 | 1.24 | 352.3 | 3176.92 |
| S18 | 0.62 | 0.10 | 150.0 | 2776.20 |
| S19 | 0.39 | 0.83 | 401.8 | 3282.19 |
| W1 | 383.73 | 0.52 | 54.8 | 229.51 |
| W2 | 383.73 | 28.65 | 55.2 | 233.55 |
| W3 | 0.39 | 0.83 | 94.4 | 395.61 |
| W4 | 383.73 | 6.05 | 56.4 | 236.59 |
| W5 | 383.73 | 5.44 | 56.4 | 236.54 |
| W6 | 350.03 | 4.44 | 147.4 | 621.22 |
| W7 | 350.03 | 6.06 | 147.4 | 621.14 |
| W8 | 73.55 | 27.30 | 147.9 | 624.61 |
| W9 | 73.55 | 26.00 | 147.9 | 624.53 |
| W10 | 276.48 | 161.90 | 150.5 | 644.49 |
| W11 | 276.48 | 107.50 | 151.3 | 644.49 |
| W12 | 32.02 | 25.00 | 217.5 | 932.82 |
| W13 | 32.12 | 24.00 | 90.0 | 378.77 |
| W14 | 0.00 | 27.30 | 147.9 | 624.61 |
| W15 | 0.00 | 6.05 | 56.4 | 236.59 |
| W16 | 0.00 | 6.05 | 56.4 | 236.59 |
| W17 | 0.00 | 6.05 | 56.4 | 236.59 |
| W18 | 22222$m^3$/hr | 2.63 | 41.49 | 173.99 |
| W19 | 22222$m^3$/hr | 2.13 | 50.55 | 211.84 |

## 5. PERFORMANCE ANALYSIS

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

### CALCULATIONS

5.1.1 Formulae used in calculation for all ambient temperatures:

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

Table 5.1: calculated amount of heat at each section.

| S.no | 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.

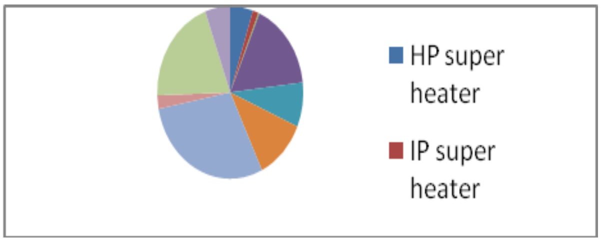


Fig 5.1: Distribution of area of each component to that of total HRSG area.

The above fig 5.1 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.

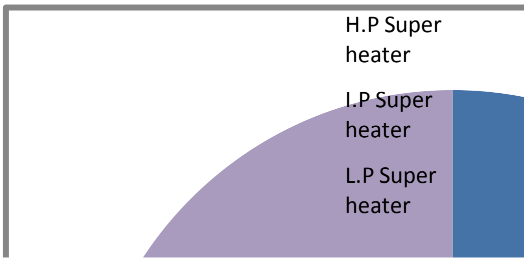


Fig 5.2: Distribution of the heat transfer of the HRSG at 15ºc

The above figure 5.2 gives the distribution of heat transfer of HRSG at 15ºc, therefore the pie diagram represented.

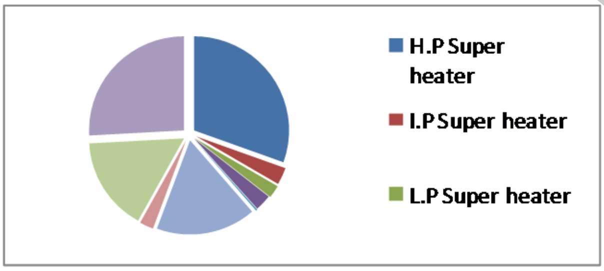


Fig 5.3: Distribution of the heat transfer area of the HRSG at 30ºc.

The above fig 5.3 gives the distribution of heat transfer area of HRSG at 30ºc, therefore the pie diagram represented.

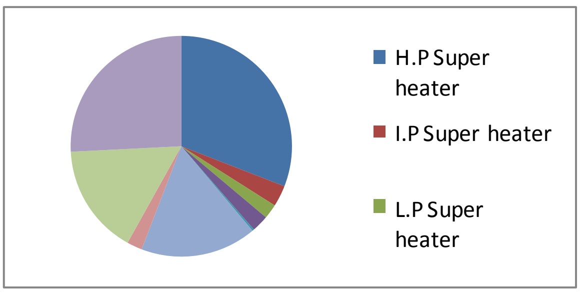


Fig 5.4: Distribution of the heat transfer area of the HRSG at 45ºc.

The above fig 5.4 gives the distribution of heat transfer area of HRSG at 45ºc, therefore the pie diagram represented

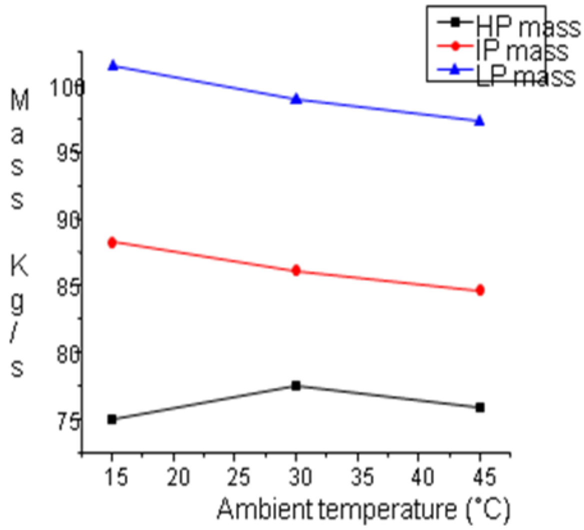


Fig 5.5: Ambient Temperature v/s Flow rate of mass of steam

The above graph gives the information regarding the mass flow rate and the ambient temperature. The mass containing in the LP is more compared to HP and IP turbines. So the mass is more in LP turbine and more power also generated from LP Turbine. This gives the importance of the individual component in the HRSG plant by means of mass flow rate. It should be reminded that variations of the flow rate and exhaust gas temperature of the gas turbine fully depend on the control algorithm of each gas turbine, which uses constant turbine inlet temperature or constant mass flow rate depending on each manufacture



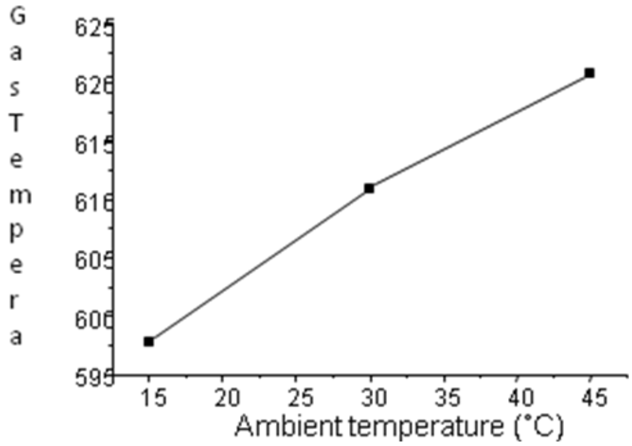


Fig 5.6: Ambient temperature v/s Gas temperature inlet to HRSG.

The graph the information as the ambient temperature increases the gas inlet temperature also increases, thus the efficiency of bottoming cycle increases. And it is come to notice that the ambient temperature has the influence on the HRSG operation. There by increasing of ambient temperature will increase the gas turbine inlet temperature.

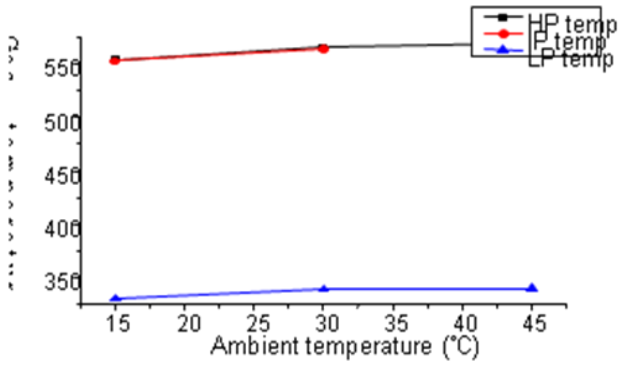


Fig.5.7:Turbine inlet temperature v/s ambient temperature

The above graph gives information regarding as ambient temperature to that of the steam inlet temperature. For LP Turbine the steam inlet temperature is low because it is last portion of the HRSG, where as the IP and HP turbines are nearer and also the reheating of the steam will increase the potential of the steam. The inlet temperature is increased with respect to the increase of the ambient temperature.

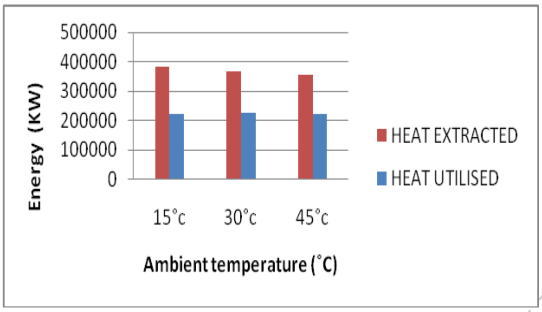


Figure 5.8: Influence of ambient temperature on energy extraction and utilization

Figure 5.8 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.

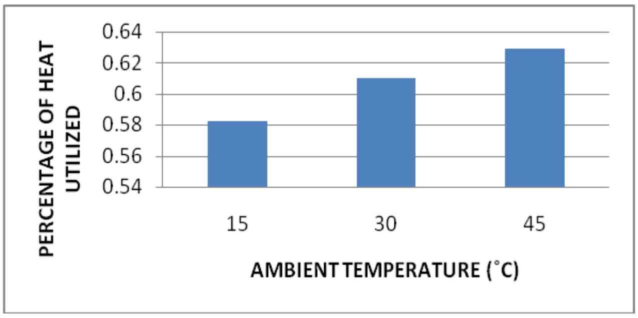


Figure 5.9: percentage of heat utilized to ambient temperature

Figure 5.9 presents influence of percentage of heat utilized to the ambient temperature as the ambient temperature increasing the heat utilization is increases because as the ambient temperature increases HRSG inlet gas temperature is increases, hence heat extraction also increases. The percentage of heat utilization is increasing with respect to the increase of ambient temperature.

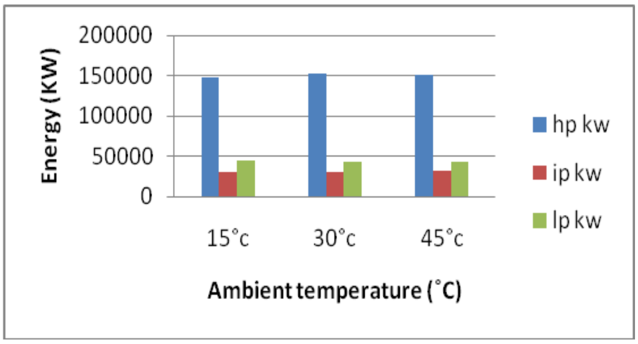


Figure 5.10: influence of ambient temperature on steam turbines heat energy utilization

Figure 5.10 presents influence of ambient temperature on that of steam turbines as the ambient temperature increases the heat energy utilized by the LP turbine goes on decreasing, heat energy utilized by the IP turbine goes on decreases and for the heat energy utilized by the HP turbine is more for the case 30°C of ambient temperature.

## 6.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 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.

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