EFFECT OF SUPPLEMENTARY HEATING ON THE PERFORMANCE OF COMBINED CYCLE

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ABSTRACT-Energy is fundamental requirement of human life, and thus a driving force of civilization so it must be utilized very efficiency at all levels. There is a great potential for increased efficiency in energy converting devices by recovering waste heat to a greater extent.

Since twentieth century the steam turbines became the most important prime mover for electricity generation. But because of their own limitations, the need of compact power plant by utilization combustion products expansion in turbine. Thus the concept of gas turbine came in to existence. It was realized that thermal efficiency of gas turbine was poor as around sixty percent of the total heat generated in combustion chamber goes waste in the exhaust. Hence it was realized that thermal efficiency of gas turbine can be improved if use of waste energy can be made to generate steam. Combined cycle power plants are gaining increasing acceptance as alternative to conventional or nuclear steam cycle due to high thermal efficiency as high as 60% utilizing natural gas as fuel. The performance of combined cycle depends upon the number of parameters like turbine inlet temp., component efficiency, turbine exhaust temp., degree of supplementary heating and condition of steam generation

In this technical paper, specific work output and thermal efficiency of combined cycle is determined at different air fuel ratio, pressure ratio and variable supplementary heating. In the present paper the pressure ratio has been taken in the range of 4 to 20 bar, air fuel ratio 50, 55, 60, and 65 and supplementary heating from 0.1 to 0.5. It is observed that specific work output and thermal efficiency improve at lower air fuel ratio, pressure ratio and supplementary heating. In the present analysis effect of supplementary heating on performance of combined cycle is discussed. It was desirable that at the (exhaust temp. of gas turbine t4a + gas turbine by passed temp.t3) should be above 813 K, otherwise the steam cycle would be inefficient resulting in lower combined cycle plant efficiency

Keywords-**A/F Ratio, Pressure ratio, Supplementary Heating, Specific work output, efficiency**

1-INTRODUCTION

In combined cycle gas turbine produces power and waste heat of its exhaust utilize to produce steam .Gas fuel can be converted in mechanical power as well as electrical power efficiently in gas turbine. Some alternate fuels also can be used in this generally diesel uses as alternate fuel.

Now days, improvements has done in efficiency of simple cycle and price of natural gas decreases, for power generation gas turbine came into trending, generally in combined cycle power plant, where exhaust gas use to produce steam, and it is use to produce extra electrical power.

This arrangement called a Combined Cycle. In the Combined Cycle in gas turbine gas burning takes places and produces power by coupling generator and also produce high temperature exhaust gas which will utilize for stream generation .

Now to use this high temperature and having huge amount of heat energy we use water cooled heat exchanger to generate steam which will utilize to run steam turbine for power generation , this type power plant is now became requirements for such countries where the natural gas available in large amount, this system produces high power outputs and high efficiency upto 60% with very low emission . On other hand in Conventional power plant only 33% electricity produces and remaining 67% as waste.

In combined cycle power plant there is possibility to produce68% electricity. It should be also done by utilizing the steam of the boiler to heat so the power plants can operate to supply electricity alone or in (CHP) mode.

2-PROBLEM DEFINITION

In this paper effect of supplementary heating on combined cycle power plant analysis is done for various a/f ratio and pressure ratio in order to find out the optimum condition for which maximum possible efficiency and workout can be achieved

3-METHODOLOGY

In the present analysis of combined cycle the effect of various parameters like a/f ratio, pressure ratio, supplementary heating and condition of steam generation on specific work output of steam generation are studied. The scheme employed for present study as flows.

4-WITH OR WITHOUT SUPPLEMENTARY HEATING

a) Without reheat without supplementary heating for steam condition of 20 bar 813 K.
b) Without reheat with supplementary heating for steam condition of 20 bar 813 K.
To analyze the present study the methodology adopted as follows:-

$Work_{net1}$ and $efficiency_1$ at different a/f ratio and pressure ratio has been calculated without supplementary heating and with supplementary heating.

We consider open cycle gas turbine in which air is taken from ambient condition of 1 bar 288 K and compressed to pressure P_2 and temperature T_{2a}. This compressed air is passed to combustion chamber where cost and conditions are maintained such as $P_3 = P_2$. Here 1kg of fuel (naphthalene) is burnt to raise the temperature of resulting flue gas to "T_3". Now P_3, T_3 condition of flue gas solely depends upon a/f ratio and pressure ratio. One part of flue gas at high temperature "T_3" and pressure P_3 is by pass to H.R.S.G and other part is expanded in a turbine up to atmospheric pressure and temperature T_{4a}. If should be noted that T_2, T_{2a}, T_3, T_{4a}, P_2, P_3, P_4, all are variables and their value would be different for different a/f ratio and pressure ratio.

A part of flue gas that by pass the gas turbine and directly goes in H.R.S.G and gas turbine exit flue gas which goes to H.R.S.G is used to generate steam. The effect of such arrangement is that worknet 1 and efficiency 1 decreases to facilitate more steam generation..Now steam is generated at 20 bar 813 K.Once the required conditions for generation of steam are met the steam cycle would contribute.

Thus we can calculate $work_{net2}$ and $efficiency_2$.

Therefore

$Work_3 = Work_{net1} + Work_{net2}$

$Efficiency_3 = Efficiency_1 + Efficiency_2$

The analysis helps us to know the additional specific work output and efficiency obtained by waste heat and supplementary heating.

In the present analysis we have calculated the work output and thermal efficiency per kg of flue gas but as mass of fuel is negligible in comparison to mass of air so we assume the work output per kg of flue gas equivalent to specific work output.in the present analysis we consider only positive values of specific work output and thermal efficiency.

5-COMBINED CYCLE ANALYSIS

The performance of combined cycle measured in terms of specific work output and thermal efficiency depends upon number of parameters. If all the parameters are taken into account in calculating specific work output and thermal efficiency it would be very tedious job.

6-ASSUMPTIONS

In order to analyze combined cycle certain assumption are made. They are

1. The change in the kinetic energy and potential energy of the working fluid between inlet and outlet of each component is negligible.
2. There is no pressure loss in inlet ducting, combustion chamber, exhaust ducting and duct connecting the component.
3. The ambient condition assumed is 1 bar and 288 K.
4. The maximum temperature permissible in gas turbine is 1400K.
5. The isentropic efficiency of both compressor and Turbine is 85%
6. The fuel assumed is naphthalene having l.C.V. = 43963.5 KJ.
7. The mass of fuel burnt in combustion chamber is 1 kg.
8. The value of specific heat of flue gas is taken as C_{pg} = 1.148.
9. In supplementary heating bypass ratio za= 0.1 to 0.5.
10. Only energy of exhaust and by passed fuel gas is used generating the steam and no addition fuel is burnt to generate the steam temperature.
11. The minimum temperature possible for the exhaust is 413 K which is the stack temperature. Steam is generated at 20 bar 813 K.
12. The condenser pressure assumed is 0.07 bar. The whole energy of exhaust is utilized in generating the steam and no energy loss place.
13. The mass of fuel burnt in combustion chamber is 1 kg.
14. The value of specific heat of flue gas is taken as C_{pg} = 1.148.

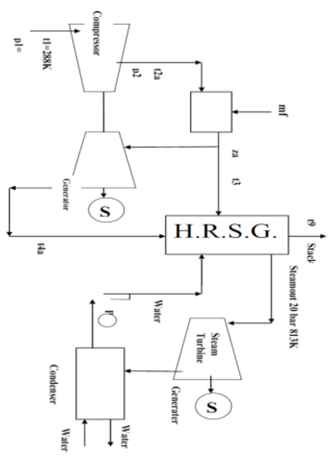

Fig.3.1 Single pressure combined cycle with supplementary heating flow diagram

Analysis

The combined cycle analyzed easily if we compute work in gas turbine cycle and steam cycle.

a) Without reheat without supplementary heating

For gas turbine work & efficiency

$W_T = (m_a + m_f) \times C_{pg} \times (T_3 - T_{4a})$

$W_C = m_a \times C_{pg} \times (T_{2a} - T_1)$

$Work_1 = W_T - W_C$

$Work_{net} = Work_1/(m_a + m_f)$

$Efficiency_1 = Work_1/(m_f \times l.c.v)$

For steam turbine work & efficiency steam is generated at 20 bar 813 K

$m_w = (m_a + m_f) \times C_{pg} \times (T_{4a} - T_9)/(h_1 - h_{f3})$

If ($T_{4a} > 813$ & $T_3 < 1400$)

$Work_2 = m_w (h_1 - h_2)$

$Worknet_2 = Work_2 / (m_a \times m_f)$

$Efficiency_2 = Work_2/(m_f \times l.c.v)$

Now

$Work_3 = Work_{net1} + Work_{net2}$

$Efficiency_3 = Efficiency_1 + Efficiency_2$

$Work_2 = m_w \times (h_l - h_2)$

$Work_{net2} = Work_2/(m_f \times l.c.v)$

Now

$Work_3 = Work_{net1} + Work_{net2}$

$Efficiency_3 = Efficiency_1 + Efficiency_2$

b) Without reheat with supplementary heating

Gas turbine work and efficiency

$W_T = z \times (m_a + m_f) \times C_{pg} \times (T_3 - T_{4a})$ Where $z = 1 - za$

$W_C = m_a \times C_{pa} \times (T_{2a} - T_1)$

$Work_1 = W_T - W_C$

$Work_{net1} = Work_1/(m_a + m_f)$

$Efficiency_1 = Work_1/(m_f \times l.c.v)$

Steam turbine work and efficiency

If ($T_x > 813$ & $T_3 < 1400$)

Steam is generated at 20 bar 813 K then

$$m_w = \frac{za \times (m_a + m_f) \times C_{pg} \times T_3 + z \times (m_a + m_f) \times c_{pg} \times T_{4a} - (m_a + m_f) \times C_{pg} \times T_9}{(h_1 - h_{f3})}$$

7-RESULT & DISCUSSION

As the pressure ratio increases keeping a/f ratio constant, turbine exit temp (T_{4a}) goes on decreasing because although T_3 increases with pressure ratio but this effect is marginalized by the increase of expansion ration owing due to higher pressure ratio.

At a particular pressure ratio if we opt a higher a/f ratio then turbine maximum temperature (T_3) goes on decreasing as the mass of fuel is constant and if we employ higher a/f ratio then heat released due to combustion of same mass of fuel is used for raising the temp. Higher quantity of flue gas results in low temperature of turbine inlet temp. The effect of supplementary heating for generation of steam required for steam turbine specific work output and efficiency varies with the variation of pressure ratio and supplementary heating. gas turbine specific work output and efficiency decreases and steam turbine work output and efficiency marginally increases resulting in increased specific work output and efficiency of combined cycle at lower air fuel ratio.

At air fuel ratio 50

1. At pressure ratio 4 $work_{net1}$ and $efficiency_1$ is maximum initially and goes on decreasing, $work_{net2}$ and $efficiency_2$ increases with the variation on supplementary heating resulting decrease in $work_3$ and $efficiency_3$.
2. At pressure ratio 6 $work_{net1}$ and $efficiency_1$ is maximum initially and decreases sharply, $work_{net2}$ and $efficiency_2$ increases up to Za = 0.1 supplementary heating results $work_3$ and $efficiency_3$ reaches at max. Value (Za= 0.1).
3. At pressure ratio 8 to 14 $work_{net1}$ and $efficiency_1$ is maximum initially and decreases sharply, $work_{net2}$ and $efficiency_2$ increases. When supplementary heating Za = 0.2 resulting increase in $work_3$ and $efficency_3$. Its max. Value is at pressure ratio 14.
4. At pressure ratio 16 to 20 $work_{net1}$ and $efficiency_1$ is maximum initially and goes on decreasing, $work_{net2}$ and $efficiecy_2$ increases. Supplementary heating results decrease in $work_3$ and $efficiency_3$.

At air fuel ratio 55

1. At pressure ratio 4 $work_{net1}$ and $efficiency_1$ is maximum initially and goes on decreasing, $worknet_2$ and $efficiecy_2$ increases with the variation of supplementary heating Za = 0.2, resulting increase in $work_3$ and $efficiency_3$ to max.value.

2. At pressure ration 6 $work_{net1}$ and $efficiency_1$ is maximum initially and decreases sharply, $work_{net2}$ and $efficiency_2$ increases. Supplementary heating Za = 0.2 resulting increase in $work_3$ and $efficiency_3$ to max. Value.

At pressure ratio 8 to 20 $work_{net1}$ and $efficiency_1$ is maximum initially and decreases sharply, $work_{net2}$ and $efficiency_2$ increases. Supplementary heating result decrease in $work_3$ and $efficiency_3$

At air fuel ratio 60

At pressure ratio 4 $work_{net1}$ and $efficiency_1$ is maximum initially and goes on decreasing, $work_{net2}$ and $effieciency_2$ increases with the variation of supplementary heating Za =0.3, resulting increase in $work_3$ At air fuel ratio 60

1. At pressure ratio 4 to 20 $work_{net1}$ and $efficiency_1$ is maximum initially and decreases sharply, $work_{net2}$ and $efficiency_2$ increases. Supplementary heating resulting decreases in $work_3$ and $efficiency_3$and $efficiency_3$ to max. Value.
2. At pressure ratio 6 $work_{net1}$ and $efficiency_1$ is maximum initially and decreases sharply, $work_{net2}$ and $efficiency_2$ increases. Supplementary heating Za = 0.3 resulting increase in $work_3$ and $efficiency_3$ to max value.

At pressure ratio 8 to 20 $work_{net1}$ and $efficiency_1$ is maximum initially and decreases sharply, $work_{net2}$ and $efficiency_2$ increases. Supplementary heating results decrease in $work_3$ and $efficiency_3$.

8-CONCLUSION

1. On a/f ratio 50 maximum workout and efficiency get on pressure ratio 14 and supplementary heating on 0.2
2. On a/f ratio 55 maximum workout and efficiency get on pressure ratio 6 and supplementary heating on 0.2
3. On a/f ratio 60 maximum workout and efficiency get on pressure ratio 6 and supplementary heating on 0.3
4. On a/f ratio 65 supplementary heating is not required

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