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A research paper on study the analysis of combined cycle power plant with change in gas turbine operating parameter

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Abstract: In this paper we analyze the change occurred in a combined cycle power plant. Operating parameters of the gas turbine are varied and various results are obtained and studied during this study.

INTRODUCTION

In electric power generation a combined cycle is an assembly of heat engines that work in tandem off the same source of heat, converting it into mechanical energy, which in turn usually drives electrical generators. The principle is that the exhaust of one heat engine is used as the heat source for another, thus extracting more useful energy from the heat, increasing the system's overall efficiency. This works because heat engines are only able to use a portion of the energy their fuel generates (usually less than 50%).

The remaining heat (e.g., hot exhaust fumes) from combustion is generally wasted. Combining two or more thermodynamic cycles results in improved overall efficiency, reducing fuel costs. In stationary power plants, a successful, common combination is the Brayton cycle (in the form of a turbine burning natural gas or synthesis gas from coal) and the Rankine cycle (in the form of a steam power plant). Multiple stage turbine or steam cylinders are also common.

In a combined cycle power plant (CCPP), or combined cycle gas turbine (CCGT) plant, a gas turbine generator generates electricity and heat in the exhaust is used to make steam, which in turn drives a steam turbine to generate additional electricity. This last step enhances the efficiency of electricity generation. Many new gas power plants in North America and Europe are of this type. Such an arrangement used for marine propulsion is called combined gas (turbine) and steam (turbine) (COGAS).

A single shaft combined cycle plant comprises a gas turbine and a steam turbine driving a common generator. In a multi-shaft combined cycle plant, each gas turbine and each steam turbine has its own generator. The single shaft design provides slightly less initial cost and slightly better efficiency than if the gas and steam turbines had their own generators. The multi-shaft design enables 2 or more gas turbines to operate in conjunction with a single steam turbine, which can be more economical than a number of single shaft units.

LITERATURE REVIEW

Najjar & Akyurt (1994) [1] reviewed various types of combined cycles, including repowering, integrated gasification and other advanced systems. According to this study: 1). Combined cycles boost power output and efficiency to levels that are considerably above those of steam power plants 2). Repowering, when converting an existing steam plant to combined cycle, offers savings in capital cost as compared to new construction 3). Combined cycle, when integrated with coal gasification, holds promise in converting coal into electric power in an efficient, economical and environmentally acceptable manner 4). The air-bottoming cycle (ABC), chemically recuperated gas turbine, compressed air energy storage (CAES) and compressed air storage humidification (CASH) are among advanced concepts with promise for combined cycle applications.

Horlock (1995) [2] based on thermodynamic considerations, outlined developments of 1970s and 1980s and future prospects of combined-cycle power plants. The main focus was on (i) raising the mean temperature of heat supply; (ii) minimizing the irreversibility within the heat recovery steam generator; (iii) keeping the heat loss between the two plants as low as possible.

De Lucia (1996) [3] studied gas turbines with inlet air cooling and reported that evaporative cooling could enhance the power produced by 2–4% per year, with rather low investment. Absorption cooling can enhance power production by 5-10% on yearly basis, depending on site climate, and upto 18% in the warmest month. Further the air cooling section with two-stage absorber is more effective than a single stage one, from the point of view of power increase. Besides, the single-stage unit, which requires about 50% more cooling water, has higher running costs. The integrated absorber plus evaporative cooling solution assures highest plant performance and yearly net benefit increase.

Mostafavi (1998) [4] explored the utilization of the exhaust gases of an open-cycle-twin-shaft gas turbine. The precooled cycle can work at higher compressor pressure ratio up to 37.82%, which depends on the cycle pressure ratio and the degree of precooling, and for the same compressor pressure ratio the temperature introduced to the combustion process will be lower by up to 15%, which depends on the degree of precooling.

Heppenstall (1998) [5], described and compared several power generation cycles which have been developed to take advantage of the gas turbine's thermodynamic characteristics. Emphasis has been given to systems involving heat recovery from the gas turbine's exhaust and these include the combined, Kalina, gas/gas recuperation, steam injection, evaporation and chemical recuperation cycles. Thermodynamic and economic characteristics of the various cycles are considered in order to establish their relative importance to future power generation markets. The present dominance of the combined cycle as the preferred option for a new plant is thought likely to continue.

Pilavachi (2000) [6] gave an overview of power generation with gas turbine and combined heat and power (CHP) systems and discussed various methods to improve the performance of the several types of gas turbine cycles.

Yousef S. H. Najjar (2000) [7] compared the gas turbine engine by its relatively low capital cost with steam power plants. It has environmental advantages and short construction lead time. However, conventional industrial engines have lower efficiencies especially at part load. One of the technologies adopted nowadays for improvement is the "combined cycle". Hence, it is expected that the combined cycle continues to gain acceptance throughout the world as a reliable, flexible and efficient base load power generation plant. In this article, 12 research investigations, carried out by the author and associates during the last 10 years are briefly reviewed. These cover 12 gas turbine systems which would contribute towards efficient use of energy. They entail fundamental studies in addition to applications of combined systems in industry including: the closed gas turbine cycle; the organic Rankine cycle; repowering; integrated power and refrigeration; cryogenic power; liquefied natural gas (LNG) gasification; and inlet air cooling.

Manuel Valdés (2003) [8] shows a possible way to achieve a thermoeconomic optimization of combined cycle gas turbine (CCGT) power plants. The optimization has been done using a genetic algorithm, which has been tuned applying it to a single pressure CCGT power plant. Once tuned, the optimization algorithm has been used to evaluate more complex plants, with two and three pressure levels in the heat recovery steam generator (HRSG).The variables considered for the optimization were the thermodynamic parameters that establish the configuration of the HRSG. Two different objective functions are proposed: one minimizes the cost of production per unit of output and the other maximizes the annual cash flow. The results obtained with both functions are compared in order to find the better optimization strategy.

Khaliq & Kaushik (2004) [9] carried an improved second-law analysis of the combined power-cycle with reheat and showed the importance of the parameters examined. The analysis has included the exergy destruction in the components of the cycle and an assessment of the effects of pressure ratio; temperature ratio and number of reheat stages on the cycle performance. The exergy balance or second-law approach presented facilitates the designand optimization of complex cycles by pinpointing and quantifying the losses. By placing reheat in the expansion process, significant increases in specific power output and efficiency were obtained. The gains are substantial for one and two reheats, but progressively smaller for subsequent stages.

Khaliq & Kaushik (2004) [10] presented a relatively simple and systematic methodology based on first and second law for the thermodynamic performance evaluation, of combustion turbine cogeneration gas turbine cogeneration system with reheat. The analysis of a certain case of combustion gas has proven the usefulness of the presented method for analysing the energetic and exergic performance of cogeneration plant. Reheat expansions gives significant improvement in first- and second-law efficiencies. Since the selection of. For decision-makers this methodology is useful in obtaining important cogeneration system is a complex decision involving technical as well as economic considerations thermodynamic information for proper trade-offs in comparison and selection of cogeneration systems and one can have better understanding of such systems without getting into mechanical details and component efficiencies.

Najjar (2004) [11] studied of inlet air precooler connected to the evaporator of an aqua ammonia absorption chiller which is driven by the tail-end heat recovered from the engine exhaust gases. A heat recovery boiler was used to partly recover the exhaust heat before entering the generator of the chiller. Suction air precooling in a combined system improves power output by about 21%, overall thermal efficiency by about 38% and overall specific fuel consumption by 28%. Performance of the combined system is relatively less sensitive to variations in operating variables.

Kakaras (2004) [12, 13] described three cooling methods a) evaporative cooling b) refrigeration cooling c) evaporative cooling of recompressed air. Depending on the gas turbine type, power output is reduced between 5 % and more than 10 % of the ISO rated power output (15°C) for every 10 K increase in ambient air temperature. At the same time the specific heat consumption increases by a percentage between 1.5 % and more than 4 %. It was concluded that the highest incremental electricity generation is realized by absorption intake air cooling.

In terms of the economic performance of the investment, the evaporation cooler has the lowest cost of incremental electricity generation and lowest payback period. Concerning to the cooling method of recompressed air, the results shows a significant gain in capacity, but the total cost of incremental electricity generation in this case is the highest. Because of the much higher capacity gain by the absorption chiller system, the evaporative cooler and the absorption chiller system both may be selected for boosting the performance of gas turbine based power plants, depending on the prevailing requirements of plant operator.

Massardo (2005) [14] studied design-point performance characteristics of a wide variety of combined- cogeneration power plant, with different amounts of supplementary firing, different amounts steam injection (or no steam injection), different amounts of exhaust gas condensation, etc. It was concluded that the performance of these plants is optimized by: (a) maximizing turbine rotor inlet temperature in the gas turbine; (b) optimizing the gas turbine pressure ratio for gas turbine performance; (c) optimizing steam turbine boiler pressure; and (d) maximizing steam injection in the gas turbine.

Research Methodology

Research methology of my work is given steps by steps as

- An exhaustive Literature Review is under progress in the area of combined cycle, cooling system and STIG.
- Development of mathematical modeling for topping and bottoming cycles, STIG and IAC systems. a mathematical model as 'a representation of the essential aspects of an existing system (or a system to be constructed) which presents knowledge of that system in usable form. In the present analysis I use the input variable.on the basis of my work. So I take three variable gas turbine compressure ratio, ambient air temperature and turbine inlet temperature to find out effect on the fuel consumed in kg per 100kg of air, work obtained form combined cycle and effcience of combined cycle.so those equaction which are effected with the varision of these input are collected at a one place. These equaction are taken form existing system.after that making a programme in the MATLAB to obtained output.

- Simulation studies of gas turbine – combined cycle power plant for gas turbine compression ratio , ambient air temperature and turbine inlet temperature of input conditions.when these programme are run in the MATLAB and varing the compressure ratio 8 to 20bar. Obtained the result for fuel consumed(kg) per 100kg of air, gas turbine outlet temperature, work obtained for combined cycle and combined cycle efficiency(%). After that run programme for ambient air temperature and varing the ambint air temperature from 275 to 325C after that same procedure used for turbine inlet temperature variation from 1250 to 1700C analysis it for the fule con fuel consumed(kg) per 100kg of air, work obtained for combined cycle and combined cycle efficiency(%).after that result are obtaind .

- The result are obtained the result are shown in the form of graph. On the basis of result discussion is made for the effect of these input variable on the Data collection of existing combined cycle power plants. fuel consumed(kg) per 100kg of air, gas turbine outlet temperature, work obtained for combined cycle and combined cycle efficiency(%).

RESULT ANALYSIS

Gas turbines used in the combined cycle power plants are having pressure ratios below 15. For the present analysis cycle compression ratio is varied from 8 to 20. In actual practice a gas turbine gives maximum efficiency at different pressure ratio than that for maximum work output. So the compression ratio is kept in between these two ratios. As the compression ratio is increased the maximum temperature at the outlet of compressor is increased. The fuel requirement is decreased because turbine inlet temperature is fixed (figure.1.). Gas turbine inlet temperature is fixed by the thermal stress bearing limit of the turbine blade material. If the compression ratio of the gas turbine has to be increased in that case size of the blade will be larger and inertia force will increase. To bear this larger inertia force, a strong blade base is required. In a combined cycle power plant waste heat coming out from the gas turbine may be utilized in heat recovery steam generator to generate steam which will be passed from the steam turbine to generate power.

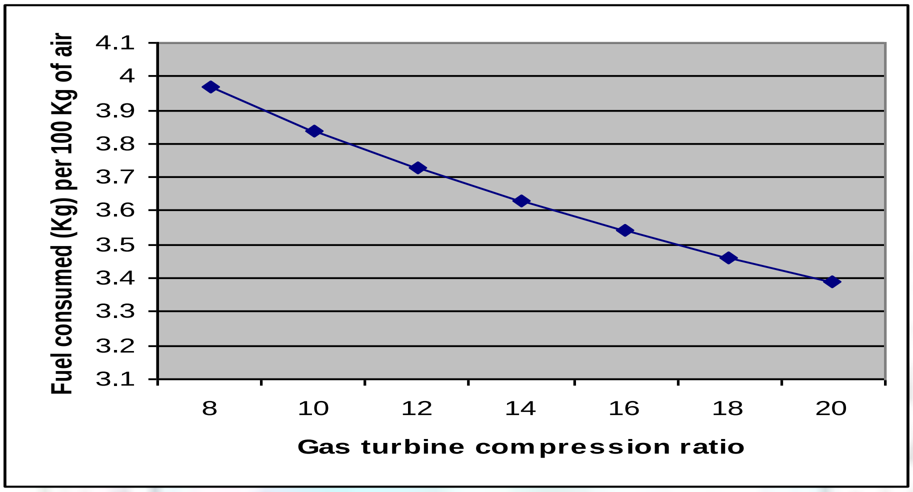

Figure 1: Change in fuel injected in combustion chamber with change in gas turbine compression ratio.

Cycle compression ratio has direct effect on gas turbine outlet temperature. As compression ratio increases, gas turbine outlet temperature decreases which make lesser heat available for pressurized water in HRSG (figure.2).

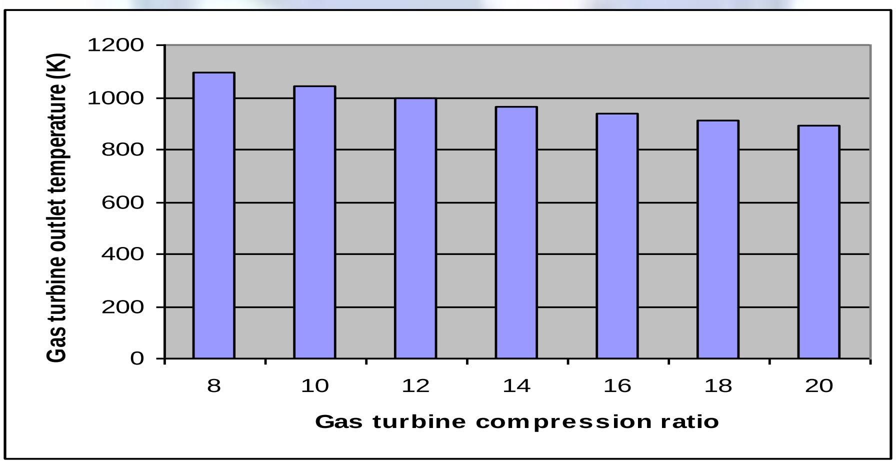

Figure 2: Change in gas turbine outlet temperature with change in gas turbine compression ratio.

For the lower cycle pressure ratio sufficient heat is available to convert the pressurized water into steam. But after a pressure ratio of 18 flue gas temperature becomes low enough to lower the heat supplied to pressurized water. Due to this steam turbine work output is decreased and after the pressure ratio of 18 a decreased work output from the cycle is obtained (figure.3.).

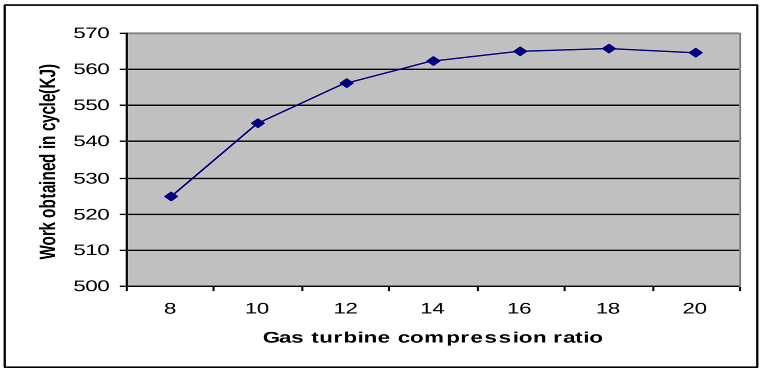

Figure 4: Change in work obtained from combined cycle with change in gas turbine compression ratio.

As it may be observed that there is not much gain in work output by changing the compression ratio but efficiency gain is reasonable (figure.6.). To calculate the cycle efficiency a ratio of work output and energy supplied is taken. As the increase in pressure ratio lower the fuel consumption so the energy supplied to the cycle decreases and efficiency increases.

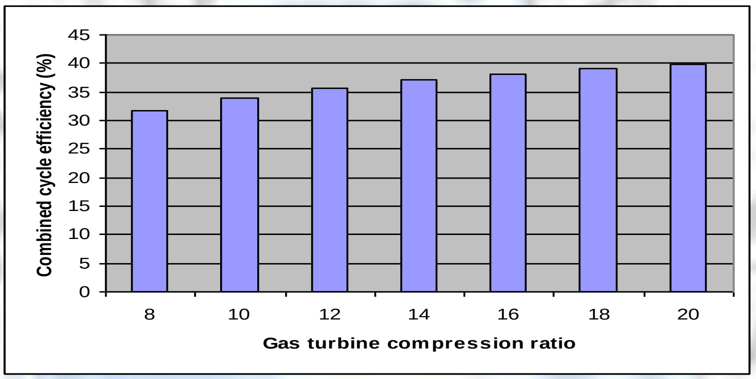

Figure 4: Change in combined cycle efficiency with change in gas turbine compression ratio.

Ambient air temperature never remains constant. Now from the analysis it is being found that as the IAT will increase fuel requirement will decrease. This is due to the fact that TIT is fixed for this case and if the IAT increases then combustion chamber inlet temperature will also increase. But combustion chamber outlet temperature is fixed. So the fuel requirement decreases .

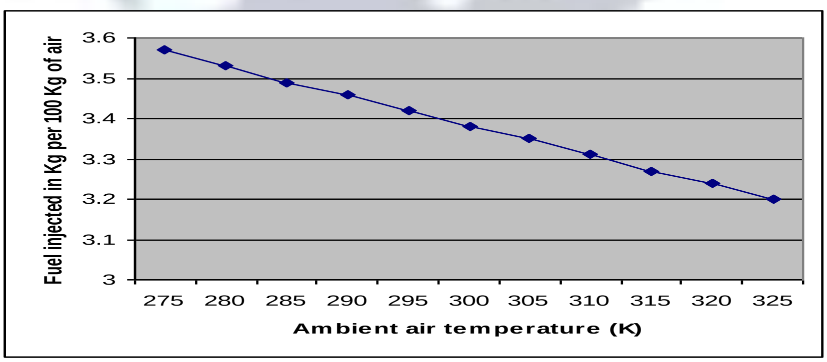

Figure 5: Change in fuel injected in combustion chamber with change in ambient air temperature.

For the design conditions if the TIT is fixed then, as the gas turbine inlet temperature will keep on increasing then the fuel requirement will decrease. But due to the increase in the ambient temperature the mass flow rate of the air to the compressor also decrease which leads to the lesser work output and lesser efficiency (figure.6.). Inlet air cooling may bring the ambient air to the designed condition.

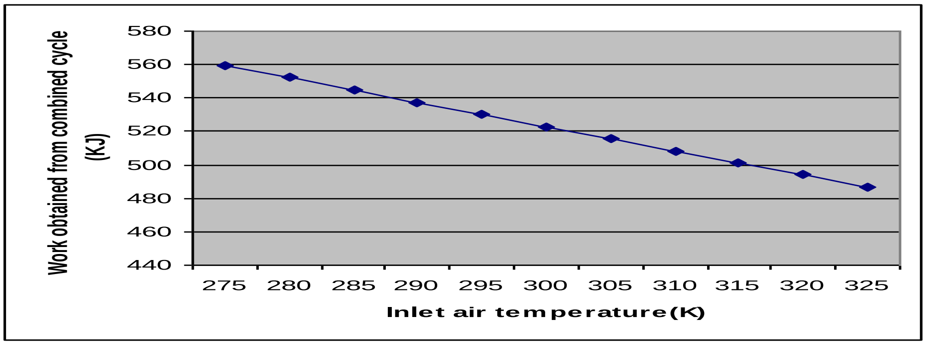

Figure 6: Change in work obtained from combined cycle with change in inlet air temperature.

Effect of increase in compression ratio is positive on the combined cycle efficiency but that of IAT is negative. With the increase in IAT combined cycle efficiency comes down. As the inlet air temperature increases, fuel consumption is not decreased much but decrease in work output is high. Due to this reason efficiency of combined cycle decreases with increase in ambient air temperature.

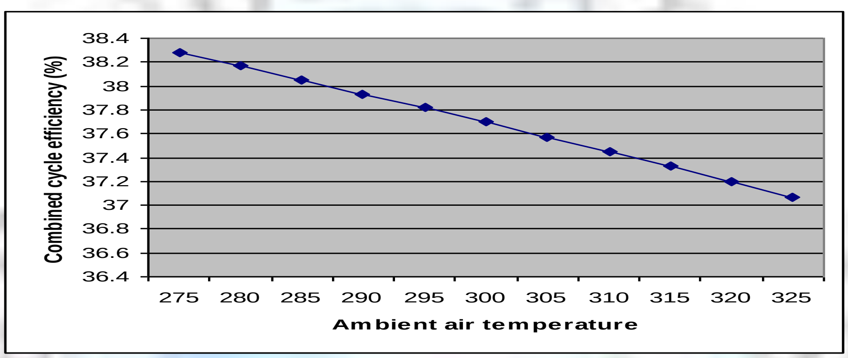

Figure 7: Change in combined cycle efficiency with change in ambient air temperature.

Highest TIT is decided by the metallurgical stress bearing capacity of turbine blade material. With the higher TIT larger is the fuel consumption and work obtained in the cycle and combined cycle efficiency also increases. For designing the gas turbine the compression ratio is kept between the maximum work and maximum efficiency. Increasing the TIT increases combined cycle efficiency. Benefit of increasing a lower temperature is more and it decreases with TIT. It is so due to increase in the consumption of fuel to attain higher TIT. After a turbine inlet temperature of 1700 K not much increase in efficiency is observed.

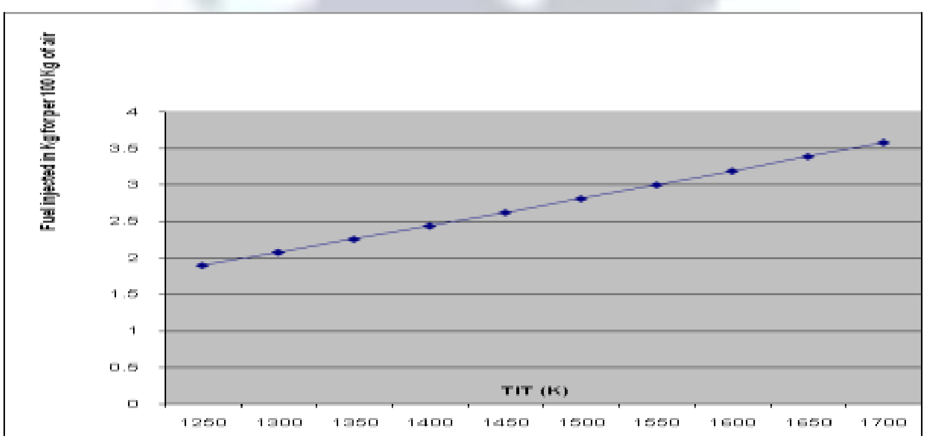

Figure 8: Change in fuel injected in combustion chamber with change in turbine inlet temperature (TIT).

In combined cycle work is obtained from the gas turbine and as well as from the steam turbine. With increase in turbine inlet temperature (TIT) work output of gas turbine is not changed but gases come out from gas turbine at higher temperature. So more heat is available in HRSG for the water to be converted into steam. Due to this reason work output of steam cycle increases and hence the net output of combined cycle.

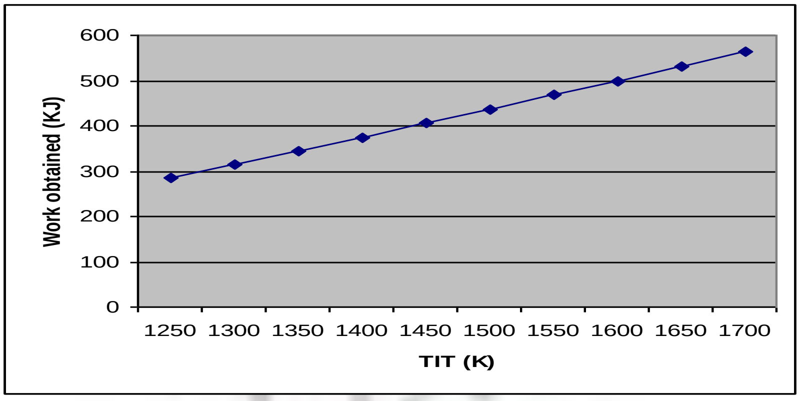

Figure 9: Change in work obtained from combined cycle with change in turbine inlet temperature (TIT).

With increase in TIT fuel consumption increases and as well as work output also increases. In this case effect of increase in work output is more pronounced than that of increase in fuel consumption. So net efficiency of combined cycle increases with increase in TIT.

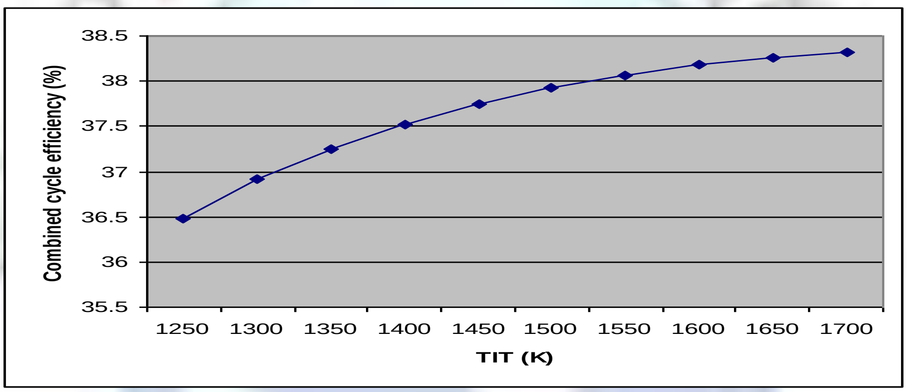

Figure 10: Change in combined cycle efficiency with change in turbine inlet temperature (TIT).

The energy analysis is not sufficient for accurate prediction of combined cycle power plant performance. Energy analysis gives only idea about the efficiency and work obtained from the cycle. It does not tell us about the major sites of energy losses. For the complete analysis exergy analysis is also required. The present work makes a base for the exergy analysis.

FUTURE SCOPE

- As futher work Methodology is needed for conversion of a **Combined Cycle Power Plant** to an Integrated Solar **Combined Cycle** (ISCC). And determine the effect on efficiency & also calclucation of electricity generated from solar plant.
- How do you design a **combined cycle power plant** As a result of it , installation **work** of main components can start earlier, and the plant can be finished faster.
- For futher work I also do exenergy analysis of combined cycle power plant.

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