Proceedings of ICFDP9:
Ninth International Congress of Fluid Dynamics & Propulsion
December 18-21, 2008, Alexandria, Egypt

ICFDP9-EG-221

COMPRESSOR INTERCOOLING USING WATER INJECTION

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ABSTRACT

In this study, a comparison is made between the traditional method of intercooling the compressor in the simple gas turbine plant using heat exchanger and intercooling with water injection. What is so peculiar of compressor intercooling using water injection over the traditional method is that mass flow rate is increased by the amount of water injected; in addition there is an increase of the specific heat capacity of the air/water mixture than that of the dry air. This ends up in an increase in the power output, efficiency and a decrease in specific fuel consumption as compared with the traditional method of compressor intercooling.

KEYWORDS:

Gas turbine
Intercooling
Water injection

INTRODUCTION

Gas turbine development work is growing very fast due to Their outstanding thermal efficiencies and other many advantages and due to the rapid rise in fuel prices much work has been made to raise the efficiency of the gas turbine as it well known efficiency is so related to fuel consumption. this paper presents one of the possible means to improve the efficiency of the gas turbine plant.

PAPER BODY

1. ANALYSIS

Three computer programs were made to simulate the operation of simple gas turbine Fig.1, traditional method of compressor intercooling using heat exchanger Fig. 2, and the new method of compressor intercooling using water injection Fig.3. using "VISUL BASIC".

Each plant is analyzed separately where each component in each plant is analyzed thermodynamically to formulate the mathematical model that simulates the operation of the plant then the mathematical model is converted into a computer model. The analysis were made taking into account change of compressor pressure ratio in the range from 2 to 14, water injection in the range from 20 C to 40 C. and the gas turbine inlet temperature was held constant to 1300 K.

A comparison was made for all the three cases considered in power, efficiency, specific fuel consumption, compressor work. The analysis was made taking the following assumptions:

- The compression and expansion processes are adiabatic.
- The change of kinetic energy of the working fluid between inlet and outlet of each component is negligible.
- The working fluid has the same composition throughout the cycle for each component and is a perfect gas.
- The change of specific heat of composition gases and air with the change of temperature of the working mediums and composition is considered.
- The heat losses and pressure drops in the combustion chamber are considered.

By knowing the compressor delivery pressure, composition of the fuel and calculating fuel/air ratio from the combustion calculation we can get the gas turbine inlet temperature and thus it will be possible to determine gas plant efficiency and specific fuel consumption.

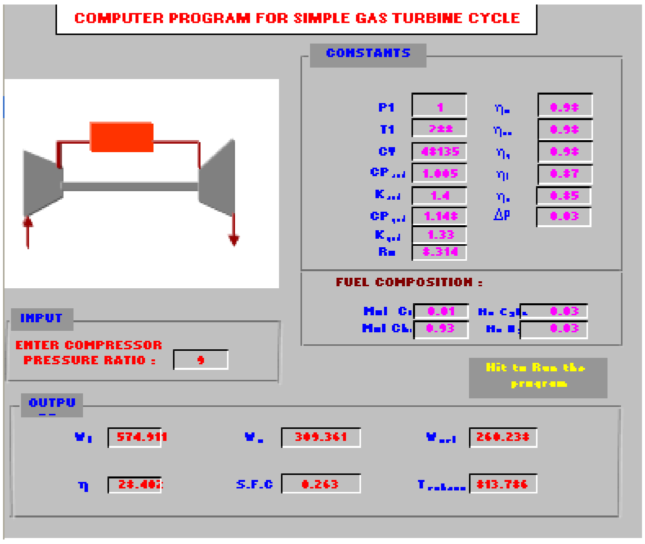


Fig.1 Simple gas turbine program

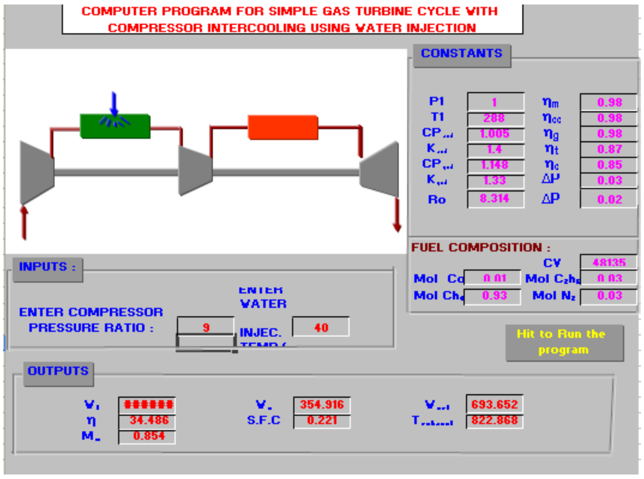


Fig.2 Compressor Intercooling Using Water Injection

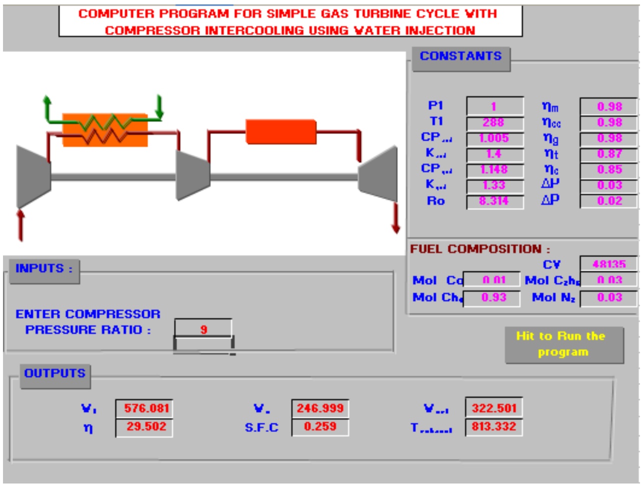


Fig.3 Compressor Intercooling Using Heat Exchanger

2. COMPRESSOR INTERCOOLING USING WATER INJECTION

In this method the quantity of water injected is just that will reduce the temperature of the compressed air in the low pressure compressor to the inlet air temperature of the low pressure compressor.

The basic equations of intercooling are as follows

The pressure at which intercooling occurse is given by:

$$P_3 = \sqrt{P_1 * P_4} \qquad (1)$$

Where:

P_3 is the intercooling pressure.

p_1 ambient pressure.

p_4 high pressure compressor outlet pressure.

The temperature at which intercooling occurse is equal to the inlet temperature that is

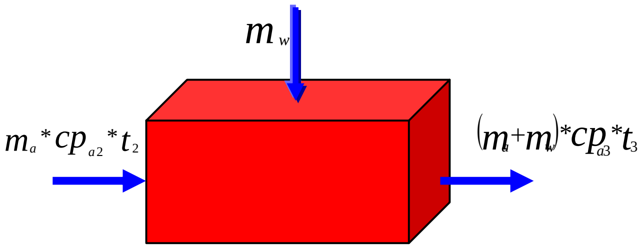
$$T_3 = T_1 \qquad (2)$$

Where:

T_3 is the intercooling temperature.

T_1 is the ambient air temperature.

Applying an energy balance on the mixing chamber to obtain the quantity



$$m_w = \frac{(cp_{a2} * t_2 - cp_{a3} * t_3)}{(cp_3 * t_3 - h_w)} \quad (3)$$

Where

m_w quantity of water injected

h_w enthalpy of water injected

The change of specific heat of composition gases and air with the change of temperature of the working mediums and composition is considered. The processes of calculation were made iteratively by assuming initial values for the specific heat of air and gases and for the ratio of specific heats. Then calculating the new values of specific heats and the ratio of specific heat for air and gases and comparing the difference between the old and new values against a certain error.

3. DISCUSION OF THE RESULTS

Figure.4 shows the change of net work of simple gas turbine, simple gas turbine with compressor intercooling using heat exchanger and simple gas turbine with compressor intercooling using

Water injection at different temperatures with different values of compressor pressure ratio at constant gas turbine inlet temperature (1300 K). As shown in the figure, compressor intercooling of the gas turbine leads to an increase of the gas turbine net work than that of the gas turbine without compressor intercooling and that of water injection is greater than that with intercooling with heat exchanger. The increase of net work in case of intercooling is mainly due to decrease in compressor work with the increase in compressor pressure ratio. While the increase of net work of compressor intercooling using water injection over intercooling with heat exchanger is due to increase in the mass flow rate by the amount of water injected along with the increase in specific heat capacity of the air water mixture. Further, the gas turbine net work with compressor intercooling using water injection increases with the increase in the of the temperature of water injected for the different values of the compressor pressure ratio due to increase of the quantity of water injected with the increase in temperature of water injected.

Figure.5 shows the effect of the quantity of the water injected at different temperatures on the fuel based thermal efficiency. As shown in the figure, the thermal efficiency of the gas turbine plant with compressor intercooling is greater than intercooling with heat exchanger for the different quantities of water injected at the different values of compressor pressure ratio. This is due to the increase in the net work.

Figure.6 illustrates the variation of specific fuel consumption of simple gas turbine with compressor intercooling at different temperatures of water injected for different values of compressor pressure ratio. The figure shows that the specific fuel consumption of the simple gas turbine with compressor intercooling using water injection is less than that with intercooling using heat exchanger for the different amounts of water being injected due to the increase in the net work.

Figure.7 shows the change of compressor work with compressor pressure ratio at different values of temperature of water injected. As shown in figure compressor work for the case of intercooling with heat exchanger is less than intercooling with water injection for the different values of water injection temperature. This is due to increase of mass flow rate of air by the amount of water injected.

Figure.8 illustrates change of quantity of water injected at different temperature with compressor pressure ratio. As shown in figure the amount of water injected increase with increase in the temperature of water injected for the different values of compressor pressure ratios.

Figure.9 demonstrates change of exhaust gases temperature with compressor pressure ratio for all the three cases considered. The figure shows that

Exhaust gases temperature decreases with the increase in compressor pressure ratio. The figure also, shows that there is no apparent change between exhaust gases temperatures for the three cases considered.

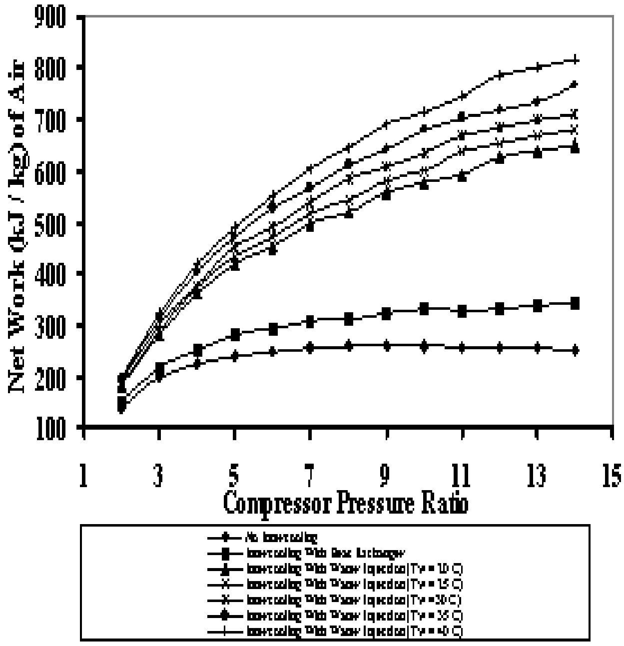


Fig.4 Change of net work with compressor pressure ratio at different temperatures of water injection.

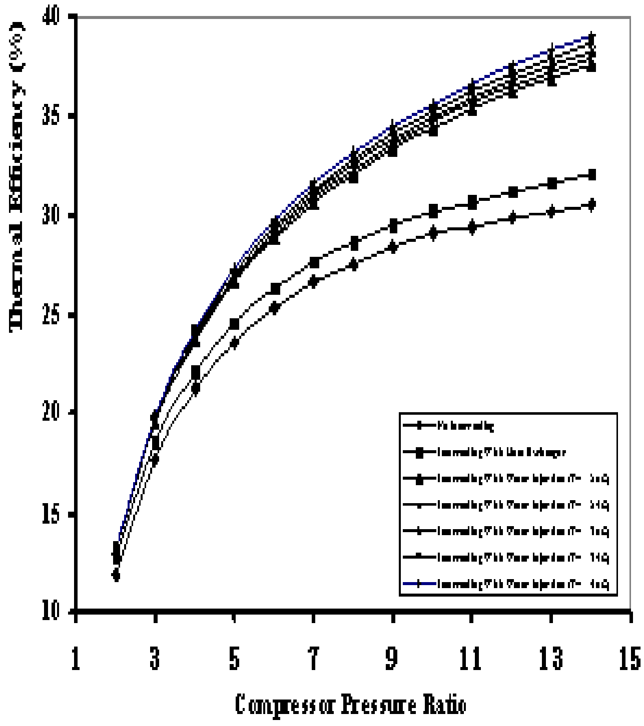


Fig.5 Change of thermal efficiency with compressor pressure ratio at different temperatures of water injection

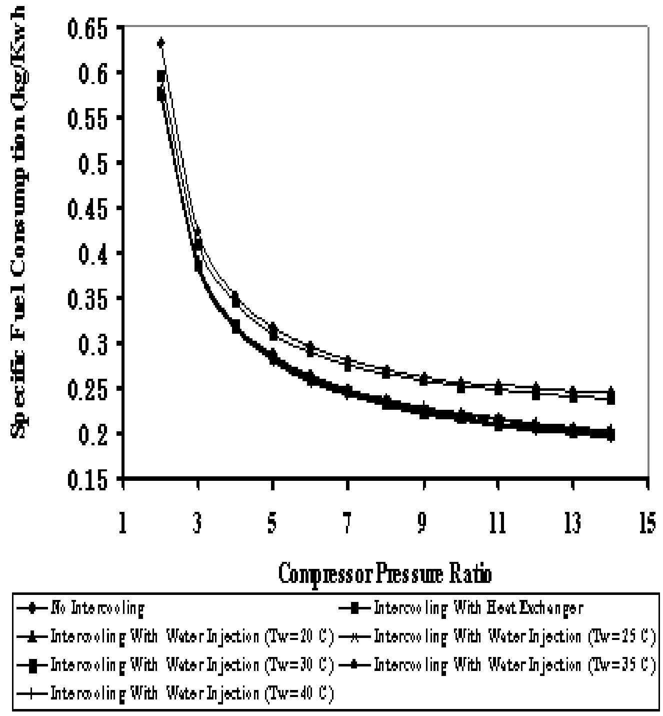


Fig.6 The variation of specific fuel consumption with compressor pressure ratio at different temperatures of water injection.

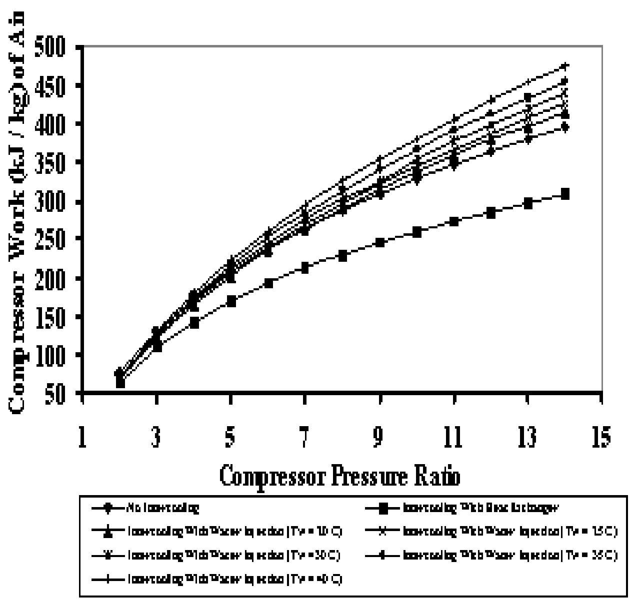


Fig.7 The variation of compressor work with compressor pressure ratio at different temperatures of water injection.

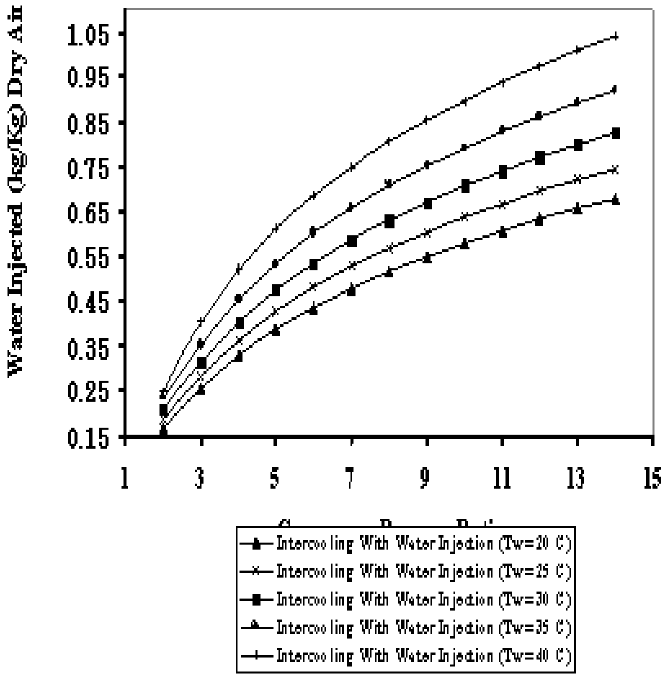


Fig.8 Change of amount of water injected with compressor pressure ratio at different temperatures of water injection.

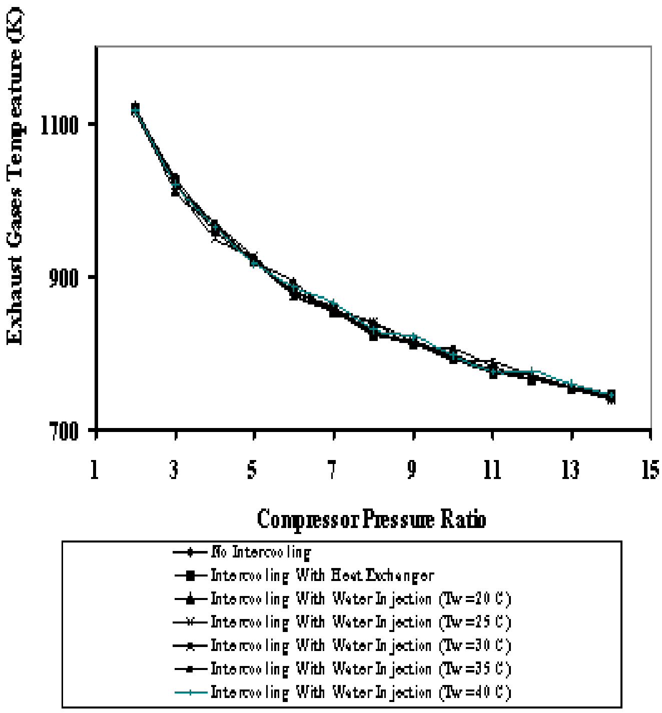


Fig.9 The variation of exhaust gases temperature with compressor pressure ratio at different temperatures of water injection.

4. CONCLUSIONS

From the previous discussion it appears that compressor intercooling with water injection offers a significant enhancements in net work, efficiency and specific fuel consumption, and these enhancement in performance is great when the water injected is heated this due to increase in the amount of water injected with increase in temperature of water injected. As the temperature of water injected is raised its enthalpy increases thus the amount of water injected increase as eq. (3) shows.

NOMENCLATURE

AF	air to fuel ratio
C	specific heat capacity (kJ/kg. K)
CV	lower heat value of the fuel (kJ/kg)
h	specific enthalpy – heating value (KJ/kg)
p	pressure (bar)
p	power (MW)
R	gas constant (kJ/kg K)
T	temperature (K)
v	specific volume (m^3/kg)
W	specific work (kJ/s)
γ	Ratio of specific heats
η	Efficiency
π	Pressure ratio
λ	Excess air factor

ACKNOWLEDGMENTS

I would like to thank Dr. Ahmed Farouk for his encouragement to let me participate in this conference and his valuable suggestions in presenting the paper with the proper format. Finally, i wish to him all the success he wishes.

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ANNEX A

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