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Impact of Fuels on Performance and Efficiency of Gas Turbine Power Plants

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Abstract

A computational study to assess the performance of different gas turbine plants is presented in this paper. The work includes the effect of relative humidity, ambient inlet air temperature and types of fuels on gas turbine plants. Investigation also covers economic analysis and effect of fuels on emissions. Gas turbine frames of various ratings are used in gas turbine power plants in Saudi Arabia. 70 MW_e GE-6101FA and 40 MW_e GE-6561B frames are selected for the present study. GT PRO software has been used for carrying out the analysis including; net plant output and net efficiency, break even electricity price, break even fuel LHV price, carbon emissions etc., for a given location of Saudi Arabia. The relative humidity and ambient inlet air temperature have been varied from 30 to 45 % and from 80 to 100° F, respectively. Fuels considered are natural gas, diesel and heavy bunker oil. Simulated gas turbine plant output from GT PRO has been validated against an existing gas turbine plant output. It has been observed the simulated plant output is less than the existing gas turbine plant output by 5%.

Results show that variation of relative humidity does not affect the gas turbine performance appreciably for all types of fuels. For 70 MW_e frame, for a decrease of ambient inlet air temperature by 10 °F, plant net output and efficiency have been found to increase by about 5 and 2 %, respectively for all fuels. More specifically, plant net output and efficiency for natural gas are higher as compare to other fuels. For given 70 and 40 MW_e frames, break even fuel price and electricity price have been found to vary from 2.03 to 2.54 US$/MMBTU and from 0.021 to 0.0254 US$/kWh respectively. It has been noticed that turbines operating on natural gas emit less carbon relatively as compared to other fuels.

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Keywords: Ambient air temperature, efficiency, gas turbines, fuels, emissions.

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1. Introduction

Gas turbines are widely used for power generation globally. In hot and dry air climates, such as gulf countries including Saudi Arabia, gas turbine engine power output is dramatically reduced because of the reduction in gas turbine air mass flow due to high inlet air ambient temperature. Cooling the inlet air to the wet bulb temperature will increase the density of the air and air mass flow, and hence will boost the power and efficiency of the plant. Different cooling technologies available for cooling inlet air are fogging, chilling, evaporative cooling etc. However, in recent past, inlet fogging technology is being employed world-wide to reduce the inlet ambient air temperature [1-3]. Also, considerable amount of research is being carried out on gas turbines (impact of fuels, impact of fogging, etc.) worldwide [4-15].

The initial discussion on inlet fogging of gas turbine was made by Chaker et al [1-2]. Fog inter cooling which has been applied from the early days of gas turbines and jet engines, is a technique that consists of spraying more fog than that will evaporate under the given ambient air temperature and humidity conditions so that non-evaporated liquid water droplets enter the compressor. The desired quantum of un-evaporated fog is carried with the air stream into the compressor, where it evaporates and reduces inter-cooling effect. The resulting reduction in the work of compression can give significant additional power boost [1-2].

Chaker et al [3], performed experimental and theoretical studies on impaction pin fog nozzle used for gas turbine inlet fogging and the dynamics of inlet fogging in general. It has been shown that ambient humidity levels do not significantly affect droplet size. Sanjeev [4] has presented the thermodynamic benefits of wet compression and performance results of the system application on a GE frame 6B combustion turbine in which the power output is augmented by 9 %. Wet compression is a process in which water droplets are injected into the compressed inlet air and allowed to be carried into the compressor. As the water droplets evaporate in the front stages of the compressor, they reduce the air temperature and therefore reduce the amount of work that must be done by the compressor air foils to pass the flow on to the next stage of compressor blades. The net effect is reduction in compressor work [4].

A review of the basic principles and practical aspect of fogging technology can be found in Meher-Homji and Mee [5] & [6]. Bhargava et al [7] have presented a comprehensive review on the current understanding, analytical, experimental and field experience of the high-pressure inlet fogging technology for gas turbine applications. The study also highlights that the ambient temperature strongly influences the gas turbine performance with power output dropping by 0.5 to 0.9 % for every 1 °C rise in temperature. A brief discussion on the status of development in the area of fogging by major gas turbine manufacturers has also been presented.

Atsushi et al. [8] investigated optimal operational strategy for an existing gas turbine cogeneration plant with steam injection inlet air cooling. The investigation was carried out for various power demands and ambient air conditions. It has been found that adoption of inlet air cooling is effective under high temperature or low humidity of the ambient airfor varying loads. Literature indicates that type of fuels used in gas turbine plants influences performance and efficiency of the plant [12-15].

The present work involves performance assessment of different gas turbine power plants. The work includes the effect of relative humidity (RH), ambient inlet air temperature and types of fuels on performance of gas turbine plants. Investigation also covers economic analysis and effect of fuels on emissions. The study has been carried out for a given location (for selected gas turbine frames, for predefined fuels) using GT PRO software based on available data/information. GT PRO is a popular software widely used for designing gas turbine power plants [9].

Gas turbine frames of various ratings are being used in gas turbine plants in Saudi Arabia. 70 MW_e GE-6101FA and 40 MW_e GE-6561B frames are selected for the present study. GT PRO has been used to carry out the simulations (eg, calculation of heat balance, cost estimation of the power plant, etc.). Also, GT PRO software has been used to analyze plant net output, net efficiency, break even electricity price (BEEP) and break even fuel LHV price (BEFP), emissions, etc.

2. Methodology

Gas turbines are constant volume machines. At a given shaft speed they always move the same volume of air, but their power output depends on the mass flow through the turbine. During hot days, when the air is less dense, power output drops. By cooling the air, mass flow is increased, thus increasing the power output. Also, about 66% of the power produced by the turbine is needed to drive the compressor [1-4]. If the air is cold, the power required by the compressor is less hence more power will be available at the turbine output shaft.

Fogging technique is widely used to reduce the inlet air temperature of compressor. Fogging system sprays atomized water into the gas turbine inlet air. The fog is generated by forcing water at high pressures (100 ~ 200 bar) through minute holes in arrays of nozzles, arranged across the gas turbine inlet ducting [10-11]. System configuration simulated in the present study is shown in Fig. 1a. Typical gas turbine performance curves are shown in Fig. 1b. It can be seen that as ambient inlet air temperature decreases, power output and air flow increase. Whereas, heat rate and exhaust gas temperature increase with increase in ambient temperature.

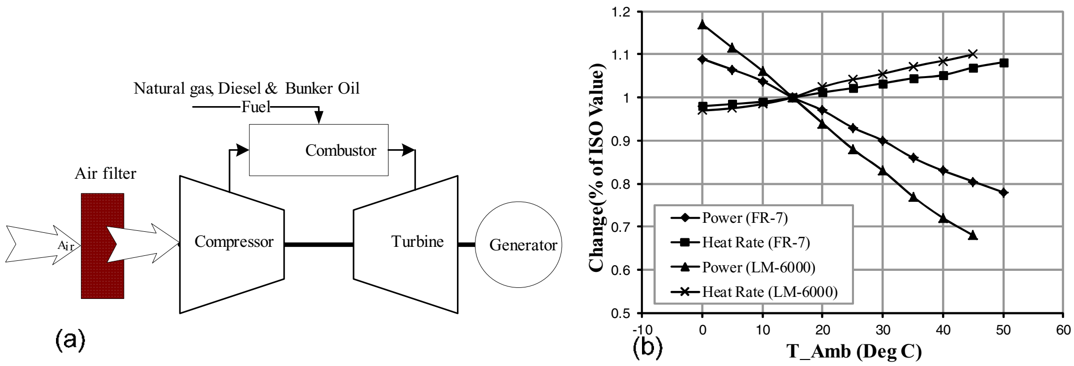

Fig. 1. (a) Gas turbine configuration used in the study, (b) Effects of ambient temperature on the performance of Gas Turbines [11].

Commonly used gas turbine frames in Saudi Arabia are listed in Table 1. Gas Turbine inputs and Plant criteria such as fuel type, ambient temperature, ambient pressures and ambient relative humidity etc, are assumed in accordance with the site location. Assumed project life, operation hours per year and load factor are 20 year, 8100 (i.e., 92% of the total hours per year, assuming 8% for maintenance/outages activities) and 100%, respectively. Study assumptions used in simulations are listed in Table 2.

Table 1.Specifications of commonly used gas turbines in Saudi Arabia

Manufacturer	Site Ratting MW_e	Name Plate Rating MW_e	Full Load Heat Rate BTU/kWh	Fuel Type
Westinghouse	67.0	92.7	14,605	gas
Gen. Electric	60	74.4	12,190	gas
Mitsubishi	46.9	63.9	16,200	gas

In order to simulate a given gas turbine plant for a given location (using GT PRO), input information to be provided includes: site specific conditions, size and type of gas turbine frame, type of fuel, fuel characteristics, pressure drops in the system, gas turbine inlet air temperature, load factor, fuel LHV buying price, electricity selling price, etc. Using the above data, simulations are performed for different inlet air temperatures (80 to 100° F)and RH (30-45%) and the results of simulations include (but not limited to); plant net output, net efficiency, heat rate, BEEP, BEFP, emissions etc.

Table 2.Study assumptions

Parameter	Detail
Air filter pressure drop	4 inch of H_2O
Fuel heating	No
Fuel compression	No
Steam injection	No
Fuels	Natural gas, Diesel & Bunker Oil
Gas turbine power as % of site rating	100
Operating hours per year	8100
First-year fuel LHV price (US$/MMBTU)	0.78
First-year electricity price (US/kWh)	0.04

3. Results and Discussions

In order to carry out the present study, General Electric gas turbine frames with rated capacities of 70 MW_e GE-6101FA and 40 MW_e GE-6561B have been selected. Several simulations were made for different scenarios using GT PRO software.

The effect of humidity on net plant output (for a given inlet air temperature 100 °F, for all Fuels, for the above gas turbine frames) is shown in Fig. 2. RH has been varied between 30- 45% (this cover the prevailing average RH range in Saudi Arabia). It can be noticed that variation of RH does not affect/improve the performance appreciably. This observation is in agreement with an earlier study [3]. Since, RH does not have much effect on the gas turbine plant performance; it has been fixed at 30% in the present study.

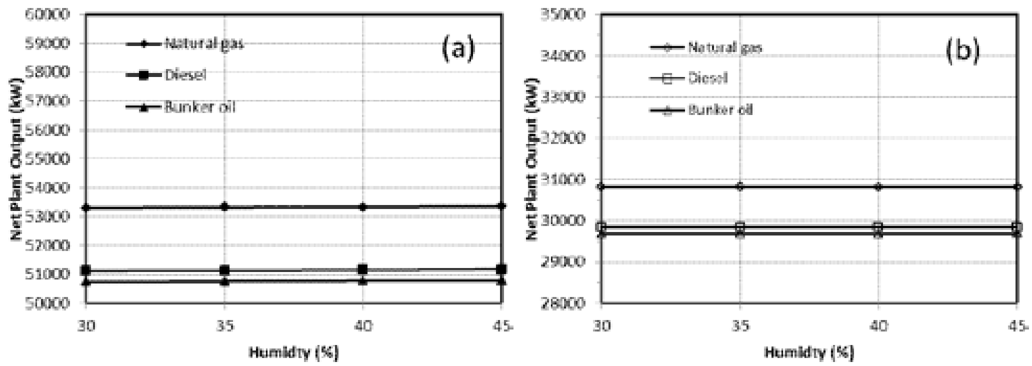

Fig. 2. Effect of humidity on net plant output [for gas turbine frames (a) GE 70MW_e GE6101FA, (b) GE 40 MW_e GE6561B, Temperature 100°F].

The effect of ambient inlet air temperature on plant net output& efficiency (for a given RH of 30 %, different Fuels) is shown in Fig. 3 and Fig. 4 for 70 and 40 MW_egas turbine frames, respectively. It can be noticed that variation of ambient inlet air temperature has significant effect on the plant net output and efficiency regardless of type of fuel. The plant net output and efficiency increase with decrease in ambient inlet air temperature. This can be attributed to the fact that with decrease in ambient inlet air temperature, air density and air mass flow increase (which eventually results in high power output). This indicates that plant net output and efficiency strongly depend on ambient inlet air temperature.

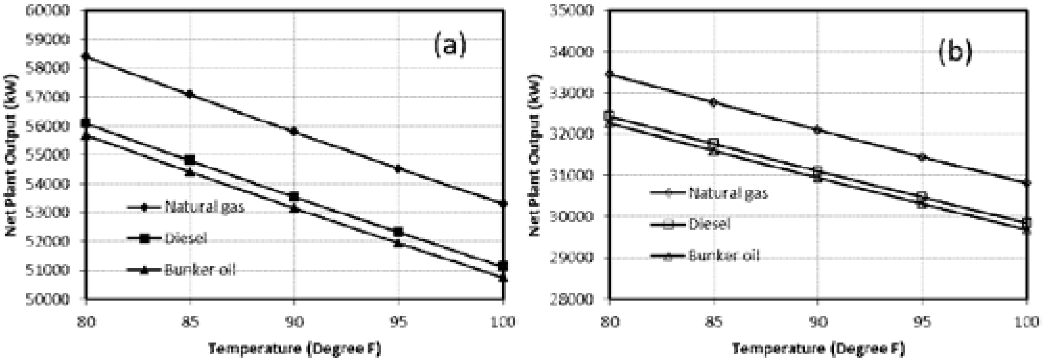

Fig. 3. Effect of temperature on net plant output [for gas turbine frames (a) GE 70 MW_e GE6101FA, (b) GE 40 MW_e GE6561B, Humidity 30%].

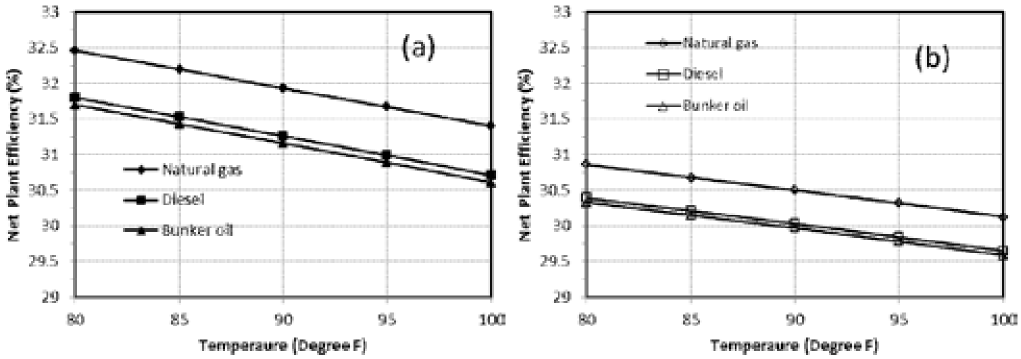

Fig. 4. Effect of temperature on net plant efficiency [for given gas turbine frames (a) GE 70 MW_e GE6101FA, (b) GE 40 MW_e GE6561B, Humidity 30%].

For a decrease of ambient inlet air temperature by 10 °F, plant net output has been found to increase by 4.1 %, and 4.6% for 40 MW_e and 70 MW_e gas turbine frames (for all fuels), respectively. Also, for a decrease of ambient inlet air temperature by 10 °F, plant net efficiency has been found to increase by 1.2 % and 1.8% for 40 MW_e and 70 MW_e gas turbine frames (for all fuels), respectively. The increment may grow further for bigger size gas turbine frames. This observation is in agreement with the findings of other research studies [7]. More importantly, observation shows that, for natural gas, plant net output and efficiency are higher than diesel and bunker oil by 4-5 % and 2-3%, respectively. In absolute terms, plant net output from a 70 MW_e gas turbine frame using natural gas has been found to increase from 53.3 to 55.7 MW_e for a decrease in temperature by 10 °F.

Ambient inlet air temperature not only has impact on plant output and efficiency, but also affects plant economics, namely, BEEP and BEFP. BEFP refers to the maximum price at which fuel can be purchased from the local market. For instance, if fuel is bought at a price higher than the BEFP then the economics of the power plant will be affected. On the contrary, BEEP refers to the minimum price at which electricity can be sold to the market. If electricity selling price is less than the BEEP price then the economics of the power plant will be affected.

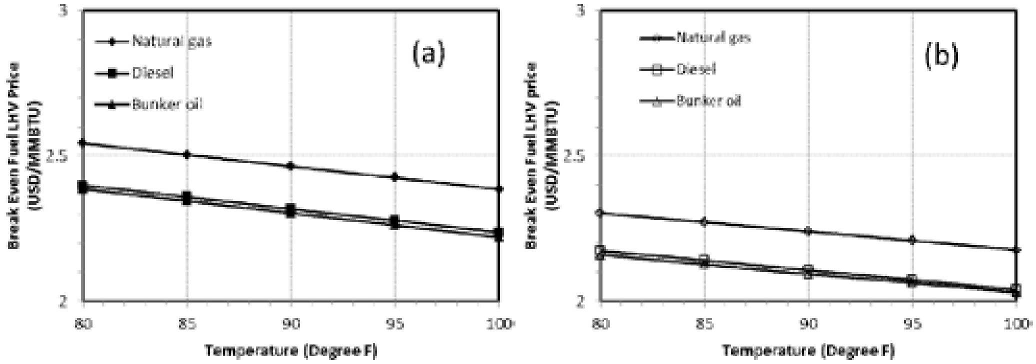

Fig. 5. Effect of temperature on break even fuel price [for given gas turbine frames (a) GE 70 MW_e GE6101FA, (b) GE 40 MW_e GE6561B, Humidity 30%].

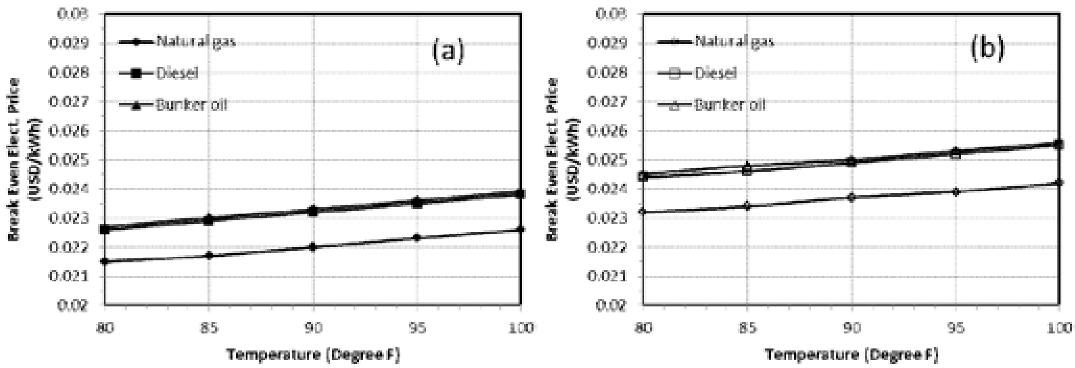

Fig. 6. Effect of temperature on break even fuel price [for given gas turbine frames (a) GE 70 MW_e GE6101FA, (b) GE 40 MW_e GE6561B, Humidity 30%].

The effect of ambient inlet air temperature on BEFP (for given RH of 30 %, for all fuels, 70 MW_e& 40 MW_egas turbine frames) is shown in Figure 5. It can be noticed that regardless of type of fuel, BEFP increases with decrease in ambient inlet air temperature. It can also be observed that the BEFP of natural gas is higher than the BEFP of other fuels. This can be attributed to higher performance and efficiency of turbines working with natural gas. For 70 MW_egas turbine frame (for 100° F ambient inlet air temperature), BEFP are 2.4, 2.3, 2.2 US$/MMBTU for natural gas, diesel and bunker oil, respectively. This implies that the fuel can be bought from the market at a higher price without affecting the economics of the plant.

The effect of ambient inlet air temperature on BEEP (for given RH of 30 %, for all fuels, 70 MW_e& 40 MW_egas turbine frames) is shown in Figure 6. It can be noticed that regardless of type of fuel, BEEP decreases with decrease in temperature. It can also be observed that the BEEP of natural gas is lower than the BEEP of other fuels. Again, this can be attributed to higher performance and efficiency of turbines working with natural gas. For 70 MW_egas turbine frame (for 100° F inlet air temperature), BEEP are 0.0226, 0.0238, 0.0239 US$/kWh for natural gas, diesel and bunker oil, respectively. This also implies that electricity produced using natural gas can be sold in the market at a lower price without affecting the economics of the plant.

The effect of ambient inlet air temperature on carbon emission (for given RH of 30 %, for all fuels, 40 MW_e and 70 MW_egas turbine frames) is shown in Figure 7. It can be observed from the figure that carbon emissions increase with decrease in ambient inlet air temperature. However, for natural gas carbon emissions are relatively less as compared to other fuels.

4. Conclusion

A computational study to assess the performance of different gas turbine power plant configurations is presented. The work includes the effect of RH, ambient inlet air temperature and types of fuels on performance of different gas turbine frames. It has been found that variation of RH does not improve the gas turbine performance for all types of fuels. For a decrease of ambient inlet air temperature by 10 °F, plant net output and efficiency have been found to increase by 5 and 2 %, respectively for the fuels considered in the study. More specifically, plant net output and efficiency for natural gas are higher as compare to other fuels. For given 40 and 70 MW_e frames, BEFP and BEEP have been found to vary from 2.03 to 2.54 US$/MMBTU and from 0.021 to 0.0254 US$/kWh respectively. It has also been noticed that turbines operating on natural gas emit less carbon relatively as compared to other fuels.

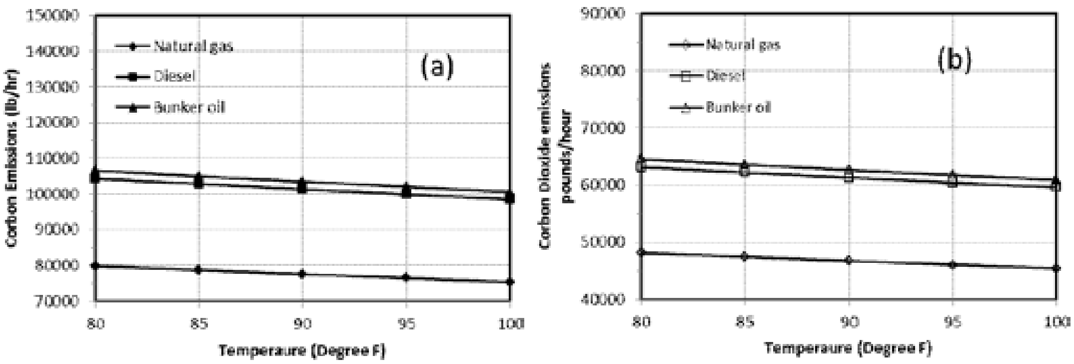

Fig. 7. Effect of fuels on emissions [for given gas turbine frames (a) GE 70 MW_e GE6101FA, (b) GE 40 MW_e GE6561B, Humidity 30%].

Acknowledgements

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