Theoretical Investigation For The Effect of Fuel Quality on Gas Turbine Power Plants

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Abstract. Gas turbine engine power generation is declined dramatically because of the reduction in thermodynamic parameters as a work of turbine, compressor ratio, compressor work, and air mass flow rate and fuel consumption. There are two main objectives of this work, the first is related with the effect of fuel kinds and their quality on the operation of fuel flow divider and its performance specifically gear pump displacement and fuel flow rate to the combustion chambers of gas power plant. AL-DORA gas turbine power plant 35MW was chosen to predict these effects on its performance MATLAB Software program is used to perform thermodynamic calculations.

Fuel distribution stage before the process of combustion and as a result of the kind and its quality, chemical reaction will occur between the fuel and the parts of the gear system of each pump of the flow divider, which causes the erosion of the internal pump wall and the teeth of the gear system, thus hampering the pump operation in terms of fuel discharge.

The discharge of fuel form the eight external gates of flow divider is decreased and varied when going to the combustion chambers, so that, flow divider does not give reliable mass flow rate due to absence of accurate pressure in each of eight exit pipes.

The second objective deals with the stage of fuel combustion process inside the combustion chamber. A comparative study based upon performance parameters, such as specific fuel consumption for gas and gasoil and power generation. Fuel poor quality causes incomplete combustion and increased its consumption, so that combustion products are interacted with the surface of the turbine blades, causing the erosion and create surface roughness of the blade and disruption of gas flow. As a result of this situation, turbulence flow of these gases will increase causing the separation of gas boundary layers over the suction surface of the blade. Therefore the amount of extracted gas will decrease causing retreat work done by turbine, as a result decline of power and gas turbine power plant efficiency causing the drop in the level of electric generation. The fuel quality is found to be a strong function of specific fuel consumption and its effects on the power generation and the efficiency of the gas turbine power plants and hence, the cycle performance shifts towards favorable conditions.
Keywords: power plant, fuel consumption, chemical reaction, flow divider, combustion

1. Introduction
Gas turbine power generating device has been widely used in the developed areas, which are growing shortage of electricity energy, in turbine power plant fuel is used as working fluid. The compressor compresses the air; heat is added to compressed air by burning fuel in the chamber. The hot and high-pressure air then passed to the gas turbine, where it expands and the mechanical work is introduced. The mechanical energy converted to an electrical energy by the gas turbine. The advantages of gas turbine of power plants are fuel flexibility, large power, and small size, lightweight, fast installation time, less investment in engineering, fuel adaptability, less pollution, and simple maintenance.

Gas turbine operates on a natural gas, synthetic gas, landfill gas, and fuel oils, the fuel must be free from chemical impurities and solids. Diesel and gas oil contain sulfur as part of their chemical make-up, this affected seriously on the efficiency of the gas power plant. While the cetane number must be maintained in a specific range where the thermal efficiency of gas turbine is a function of a pressure ratio, ambient air temperature, turbine elements, turbine inlet air temperature, and the efficiency of the compressor enhancements. All these parameters must be improving with time. High sulfur and other contaminations, low cetane number are effecting on fuel quality, is in this work we summarized the parameter affecting on the quality of fuel and how does it affection the work of power plant, which can reduce the power while the ambient temperature has the ability to change the rate of power.

M.S.AL-Rasidi, et al. [1], presented an application of the industrial source complex model for short-term prediction (ISCST3) to determine the impact of SO2 released from four power plants in Kuwait. Four different scenarios were simulated along with their corresponding real case scenarios to analyse the impact of SO2 based on the Sulphur content in the fuel used by the power plants.

The comparison with the real case scenarios show that the predicted maximum hourly average ground level concentration is about 2244.19 µg/m 3, exceeding the allowable KAAQS (hourly standard is 445 µg/m 3), whereas if the fuel used in all power plants is of 0.5% Sulphur content the standard was not exceeded and the maximum hourly predicted concentration was 370.62 µg/m 3. They concluded that there is an urgent need to identify or reduce the effect of sulfur dioxide as a fuel combustion product containing sulfur.

P. Ghosh et al. [2], presented the general composition based predictive for cetane number (CN) that can be universally applied across a wide variety of Diesel fuels, including process streams and their blend. The cetane number is correlated to a total of 129 different hydrocarbon lumps determined by a combination of supercritical fluid chromatography, gas chromatography, and mass spectroscopic methods. A total of 203 diesel fuels are considered in this study derived from various diesel-range refinery process streams and their commercial blends.

Mehaboob Basha et al. [3], employed a computational study to assess the performance of different gas turbine plants. The work includes the effect of relative humidity, ambient inlet air temperature and types of fuels on gas turbine plants. It has been observed for 70 MW 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. It has been noticed that turbines operating on natural gas emit less carbon relatively as compared to other fuels.

Wong et al. [4] studied the effect of the Ash deposits resulting from the combustion of poor fuel quality and what it causes when depositing it on the moving and stationary blades of turbine of gas stations to generate electricity. It has been observed that chemical and mechanical corrosion occurs on the surfaces of the turbine blades when the fuel is burned, causing the surfaces pitting of these blades to be damaged, which should be replaced due to its effect on the workings of the turbine and the end of its service life. They decide to take into account the economic effects when this type of fuel and caused by the products of this combustion and
suggested to replace these kinds of fuels or add some additives of materials to improve the performance of fuel when burned.

Mike Welch et al. [5] showed the presence of sodium, potassium, or vanadium, contaminants commonly found in air in off-shore or in coastal environments or in liquid fuels, further assessment will be required as the reaction of these metals and their salts with sulfur results in the production of sodium and potassium sulfates or vacates, which are highly corrosive to modern materials (for example, nickel alloys) used in the hot gas path components, such as turbine nozzles and rotor blades. Such corrosion can occur after many operating hours.

S. C. Singh [6] studied the characteristics of High temperature solid oxide fuel cells (SOFCs) and its effect on gas turbine power plant performance. They observed that this kind of fuel offers a clean, pollution-free technology to electrochemically generate electricity at high efficiencies. These fuel cells provide many advantages over traditional energy conversion systems including high efficiency, reliability, modularity, fuel adaptability, and very low levels of NOx and SOx emissions. Furthermore, because of their high temperature of operation (~1000°C), pressurized SOFCs can be successfully used as replacements for combustors in gas turbines; such hybrid SOFC–gas turbine power systems are expected to reach efficiencies over 70%. This paper reviews the materials and fabrication methods used for the different cell components, and discusses the performance of cells fabricated using these materials; it also discusses the materials and processing studies that are under investigation to reduce the cell cost.

Penyrat Chinda et al. [7] investigated the effect of Solid Oxide Fuel Cells (SOFCs) as hybrid systems on the gas turbine power plants cycle efficiency. Two models of solid oxide fuel cell and gas turbine power system have been developed based on simple thermodynamic expressions and implemented in MATLAB. They concluded that the performance of this cell is to be the strongest factor of operating temperature (which depends upon the preheating of the input streams) and hence when the heat exchanger properties are varied with the air mass flow rate, the cycle performance shifts towards favorable conditions. Therefore, the factors that control the cycle performance are the SOFC temperature, the turbine inlet temperature, and the exhaust temperature. However, at high SOFC temperatures, the cycle efficiency is high.

2. Theory of calculation:
A flow divider is composed by two or more modular elements (stages) with driving gears mechanically linked by an internal coupling sleeve that causes them to turn at the same speed. Unlike multiple pumps, in which the input power is mechanical (shaft connected to a motor), in a flow divider the input power is hydraulic, i.e. a flow under pressure supplies the modular elements, which are connected to the hydraulic circuits serving the users.

Flow dividers are used on gas turbines to maintain equal flows of liquid fuel to all combustors. They are passive devices that derive their motive power from the energy contained in the fuel delivered by the main fuel pump. Although designs and layouts vary, the fundamental principle of flow-divider operation is the same. Flow dividers are little more than an array of virtually identical, high-precision, spur-gear hydraulic motors (think of them as flow elements) that are mechanically coupled to run at equal rotational speeds, as shown in figure(1),(3)[8] and (2)[9].

Figure (1). Fuel flow divider

Figure (2). External gear pump
2.1 Displacement (Z)
Displacement is a volume displaced during one complete gear revolution (cubic inches, cubic gallons or (cubic cm/rev),[9].

\[ Z = 6\times W \times (2D-L)\times (L-D)/2 \] (1)

\( Z \) is the gear pump displacement (cm\(^3/\)rev)
\( L \) is the length of both gear displacement (cm).
\( D \) bore diameter of one of the gear chamber (cm)
\( W \) gear width (cm)

2.2 Fuel flow Rate (Q)
Measurement of fluid delivered per unit of time,[9]

\[ Q = Z\times N \] (2)

\( Q \) is the fuel flow rate (l/min)
\( Z \) is the gear pump displacement (cm\(^3\))
\( N \) is the rotation speed of flow divider per min

2.3 Pump volumetric efficiency (ηv)
Volumetric Efficiency is defined as the ratio of flow rate to the volume displaced per unit of time, so that it can express as,[9]

\[ η_v = Q_{act}/Q_{ide} \] (3)

\( η_v \) is the volumetric efficiency
\( Q_{act} \) actual fuel flow rate delivers from flow divider (l/min)
\( Q_{ide} \) theoretical fuel flow rate delivers from flow divider (l/min)

2.4 Differential pressure
The differential pressure is the algebraic difference of the discharge pressure and inlet pressure, with terms expressed in like units, [9]

\[ Δp = p_d - p_i \] (4)
Where

\( \Delta p \) is differential pressure (bar)

\( P_d \) discharge Pressure (bar)

\( p_i \) Inlet Pressure (bar)

The pump tasks the power from a rotating shaft as shown in eq.(5)

\[ P_{in} = T \times W \quad \ldots \ldots \quad (5) \]

Where \( P_{in} \) = power input to shaft (watt) or (horsepower).

\( W = \) shaft rotational speed (rad/ sec) or (rev/min).

Apportion of this power is dissipated in the pump through coulombs friction and viscous dissipation. This is not easily quantified experimentally. This power will be denoted at \( (P_{loss}) \)

\( P_{loss} = \) (frication), viscous effect (watt or horse power)

The power output that can be derived from the fluid will come out of the pump in equation (6)

\[ P_{out} = (\Delta p \times Q) = P_{in} - P_{loss} = T \times Q \quad P_{loss} \ldots \ldots \quad (6) \]

\( P_{out} = \) the power output to fluid system (watt or horsepower).

\( \Delta p = \) pressure increase between inlet and outlet (PSI) or Pascal.

\( Q = \) flow rate through the pump (lit)

\( Q = \) fluid density \( \times \) pump density \( \times \) r.p.m(in/ sec), equation (6) can expressed using the efficiency in equation (3)

\[ P_{OUT} = \eta \times P_{in} \quad \ldots \ldots \quad (6) \]

Where: \( \eta \) = mechanical efficiency and \( \eta = P_{OUT} / P_{in} \). This is a function of the fluid viscosity, clearance between internal components, and other variables. Typically, gear pump efficient around (85%).

3. Thermodynamic considerations of gas turbine

Specific fuel consumption (SFC) may be defined as the ratio of fuel used to the amount of power produced by engine, [10]

\[ SFC = 3600 \times \frac{f}{W_n} \quad \ldots \ldots \quad (7) \]

\[ \eta_{in} = \frac{W_n}{f \times Q_{net}} \quad \ldots \ldots \quad (8) \]

\[ \eta_{in} = \frac{3600}{s_f \times Q_{net}} \quad \ldots \ldots \quad (9) \]

Where

SFC Specific fuel consumption (m³/MW.hr)

\( f \) fuel air ratio

\( Q_{net} \) higher calorific value at constant pressure (kJ/kg)

\( W_n \) specific network output (kW)
4. Results and discussion

Figure (4) represents the effect of impurities and pollutants for the gasoil fuel used in the operation of the gas station, which is the change in the dimension of the internal wall of the pump between the tips of the teeth, that represents the x-axis while the y-axis represents the volume displacement of pump in addition to the amount of change in the flow of fuel. It is noted that the relationship is inverse proportional where the greater the change in this distance creates the decreasing of the volume displacement of the pump and causing an increased process of fuel leakage between the inner wall and the tip of the gear teeth producing low pressure pump and thus decrease the amount of fuel flow to the outside.

This decrease in fuel flow because of the fuel consist of pollutants and impurities, which increase the chemical reaction of fuel and the wall of the internal pump, which causes the wall erosion over time and increase the internal volume. Those particles resulting from the erosion of the wall remain stuck with fuel and may enter between gears teeth cause mechanical wear and the occurrence of surface pitting of the gears teeth. Therefore, that fuel flow required will not reach the combustion chamber of the station and the occurrence of incomplete combustion of unequal combustion ratios between fuel and air. The difference in the flow of fuel from one pump to another leads to the lack of balance in the process of combustion within the eight combustion chambers of the station. This phenomenon is working to reduce the efficiency of combustion chambers to produce the temperature required that is satisfied turbine work.

Figure (4). Core length against gear pump displacement and fuel flow rate

Figure (5) shows that the gas turbine cycle efficiency is affected by specific fuel consumption, for diesel fuel. The decreasing of specific fuel consumption leads to a lower cycle efficiency. The curves represent the amount of diesel fuel spent for expected and practical situation. It is noticeable from the figure that the relationship between specific fuel consumption and efficiency is inverse proportional so that the gas turbine power plant efficiency begins to decline as the specific fuel expenditure is increased therefore, the gas power station is also decreased. The decline for the practical efficiency curve is increased and as different as expected efficiency curve because of the diesel fuel quality used, which in turn reduces the efficiency of the plant.

Figure (5). Gasoil fuel efficiency against specific fuel consumption
Figure (6) represents the variation of expected and actual specific fuel consumption. The amount of specific fuel start to decrease as the power generation of the plant increases and therefore the station’s efficiency will increase due to the nature of the inverse proportion between the specific fuel consumption and the power plant generation. However, actual fuel disbursements for the actual specific fuel consumption are greater than the expected discharge when the power generation.

Figure (6). Gasoil fuel efficiency against power generation

Figure (7) represents the change of efficiency against the variation of specific fuel consumption for two kinds of fuel, gasoil and gas during plant operation. The efficiency is declined gradually as an increasing of specific fuel consumption and varied inverse proportional linearly. The efficiency of the gas power plant is regular, highly effective and low fuel consumption during gas fuel operation, while the efficiency is lower, higher fuel consumption and less efficient if the use of diesel fuel. The reason is the purity of the gas oil and its impurities, in addition, the calorific value of gas fuel is higher than gasoil, also there is no harmful residue when the gas fuel is burned, as it is for the diesel fuel used, which seems to leave residues that interact with the surface of the turbine blades.

These waste, which are formed on the turbine blades surface as well as the high temperature inside the turbine, result in a chemical reaction with the blade surface and the formation of blade , which growth the surface roughness, thereby eroding the aerodynamic performance by increasing the region of turbulent gas flow on the blade’ surface and increasing energy the layers of the walls of those gases.

Thus, the separation of those layers, which leads to increased drag force on blade and reduce the lift and its efficiency. As a result of this phenomenon the stage efficiency will also reduce. The decline in the performance of the whole turbine stages leads to turbine's collapse blade performance and the reduction of the work done, so that the power generation will reduce and is not the same as when using pure gas fuel.

Figure (7). Gas and gasoil efficiency against specific fuel consumption
'Figure (8)' shows the relationship between the change in power generation of plant and the quantity of specific fuel consumption for both diesel and gas fuel where the correlation relationship is inverse between the change in power generation and the amount of specific fuel consumption. The higher the power generation, the less the quality of fuel consumption for both gasoil and gas, while the gasoil fuel consumption values remain lower than gas fuel at any point of power, and this shows that the efficiency of the station will be higher when using gas fuel.

![Graph showing the relationship between specific fuel consumption and power generation for gas and gasoil.](image)

**Figure (8).** Gas and gasoil specific fuel consumption against power generation

'Figure (9)' represents the relationship between the power generation and the station’s efficiency for both diesel and gas. The correlation between the power and efficiency changes is the proportional. As the power generation rise, the efficiency of the station will increases. However, the increase in the efficiency of the plant when using gas fuel is greater than the increase in diesel fuel. Efficiency is increased when the power generation of the station is 15 MW by 0.266 and continue this difference and by 25 percent between the gas and diesel fuel values until the power generation will be 23 MW. Therefore, the use of gas fuel is better to increase power generation and efficiency of the station.

![Graph showing the relationship between efficiency and power generation for gas and gasoil.](image)

**Figure (9).** Gas and gasoil efficiency against power generation

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