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Effect of Heavy Fuel Combustion in a Gas Power Plant on Turbine Performance: A Review

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ABSTRACT

The current review focuses on the utilization of heavy fuel in operating gas turbine and their effect on the power plant performance. The literature survey includes a comparison of the different studies to reveal the effect of the fuel property on the combustion efficiency and fuel consumption. the most important of which is the generation of electric power by heavy fuels in power stations that use turbines. Gas turbine is becoming increasingly widespread in electric power generation and other branches of industry. It is known that the thermal efficiency of an open gas turbine cycle varies according to the type of fuel used in the plant. Gas turbines are particularly suitable for fuels with materials that have physical and chemical properties that help in continuous combustion and therefore the ease inherent in Fuel injection and mixture preparation.

1. INTRODUCTION

The metal materials that make up the machines are exposed to various problems that they face during use over time, as the metal pieces that make up the electrical plant are exposed to the corrosion process as a result of the use of heavy fuel in them, which results in impurities that break the edges of the turbines that generate electricity [1]. The degree of corrosion of metal depends on several factors, including (the properties of the metal surface, temperature, chemical composition. There are many types of corrosion, including the corrosion that occurs at high temperatures and is called hot corrosion. High Corrosion Temperature High (Which occurs in the presence of pollutants instead of oxygen, which is similar in its work to the phenomenon of oxidation, it occurs in gas turbines, including power plant turbines, and the main reason for its occurrence is that the used fuel contains many polluting elements (vanadium, sodium, sulfur), which when heavy fuel burns lead to the formation of deposits that turn over time to ash, causing corrosion of metal pieces and reducing her age [1, 2]. Sodium, sulfur and vanadium are among the most important pollutants that result from fuel, which is in a volatile form at the start of the combustion process that occurs on the surfaces of turbines and boilers opposite the flame the most important of which is Sodium Vanadal Vanadate ($Na_2O.V_2O_5.5V_2O_5$) Which is formed in the form of deposits on the body of the turbine [3, 4].

One of the ways to resist corrosion is to use alloys that resist the corrosion process, especially hot ones, that remove vanadium and sulfur from the fuel before burning it [5, 6]. The removal sediment process is carried out by adding capable chemical compounds to raise the melting point and change the structure of the sediment, and this is exactly what happens when add container compounds on magnesium, often when any compound containing magnesium is burned, it passes through the oxide layer It decomposes and tries to bind with oxygen to form magnesium oxide (MgO), which is inhibited by molten sodium Vanadyl Vanadates by the formation of magnesium compounds Magnesium Vanadate (MgxVyOZ) which melts at degrees higher than (C) 1000), and this degree, as it is known, is higher than the degrees Thermal heat formed in the combustion chambers of turbines and commercial boilers fuel, and magnesium oxide (MgO) is A qualified for this role [7, 8]. The surveyed studies showed that there is a significant effect for the used fuel on the power plant performance and gas turbine durability. Hence, the objective of the current review is to reveal the effect of heavy fuel utilization to operate gas turbine on the power plant performance. The review aims to present detailed information of the influence of fuel property on the combustion and generated power.

Heavy oil is one of the crude oil derivatives, which is formed when refining processes obtain crude oil, Table 1 shows the components of heavy and light crude oil and the composition of medium crude oil is listed in Table 2.

Table 1. Composition of heavy and light crude oil [9, 10]

	Percent of Total Crude	
	Light oil	**Heavy oil**
Normal paraffins (alkanes)	23.3	0.95
Branched chain alkanes	12.8	3.2
Cycloalkanes or naphthenes	41.0	19.2
Aromatic (mono-and Polly)	6.4	9.5
Naphtheno-aromatics or mixed Hydrocarbons (include S compounds)	8.1	27.9
Resins Asphaltenes	8.4	23.1
Total	100	100

Table 2. Composition of medium crude oil [9, 10]

	Carbon Number and Type	BP °C	Percent of Crude
Gasoline	C5-C10 a, ia	180	25
Kerosene	C11-C13 a, ia, ca, ar	180-250	10
Gas oil	C14-C15 a, ia, ca, ar	250-300	15
Light oil distillate	C18-C25 a, ia, ca, ar	300-400	20
Lube oil distillate	C26-C35 a, ia, ca, ar	400-500	10
Residue (fuel oil, etc.)	C36-C60 a, ia, ca, ar, r, as	500	20

a=alkanes,straight chain; ar= aromatics; ia= isoalkane, branched chain; r= resins; ca=cycloalkanes as= asphaltenes.

2. HEAVY OIL FUEL COMBUSTION

The use of liquid fuels occupies a large proportion of the total energy production in the world. Where the fuel is of two types, heavy fuel and light fuel that is easy to Combustion, Considering the use of light fuel oil, there is an urgent need for the development of heavy oil combustion Which about its use in engines does not burn completely and leads to more damage to metal parts such as corrosion and blockage of pipes, this necessitates devising effective ways to treat its combustion in an environmentally acceptable manner that does not harm the engines. In order to ensure the complete combustion of the fuel in the engines, more oxygen must be pumped, the fuel must be in the form of atomizer, and the fuel compartment must be of a high temperature and appropriate to ensure complete combustion [9].

3. CORROSION

Metal corrosion is defined as the chemical effect that occurs on them in different environments, which leads to their damage and destruction. Metals always tend to be in a more stable state in their nature. During high temperatures when burning heavy fuel oil, corrosion occurs in the form of oxides that form on metals, where ash pollution and corrosion are among the main problems when burning heavy oils. Steam boilers and gas turbines used in power plants [11, 12].

The severity of erosion is affected by several factors [13], including:

A- Components of the oil with its inorganic content Such as Vanadium and Sulfer and alkali metals.

B - The excess of combustion air and the placement of gas in the face of the pipe.

C- the interface temperature of the metal layer, which determines.

The following liquid phases occur:

1- Deposits of molten and semi-molten layer at high temperature.

2- Concentrated sulfuric acid.

3.1 Corrosion of the turbines

The phenomenon of corrosion that occurs in steam boilers and turbines (electricity production stations) is familiar to the workers in those places, and it occurs in all the metal parts of the boiler or turbine material due to the accidental outputs of the fuel used [14]. These by-products (pollutants) cause corrosion in the operating units of the turbines, which can be observed over time because the corrosion is a cumulative phenomenon and not instantaneous [15]. Where liquids and acids such as (hydrochloric acid, sulfur trioxide) are formed in the water unit, causing corrosion. The corrosion process may result in a decrease in temperature [16, 17].

Magnesium can be added in the form of small particles dispersed as oxide or carbonate or as oil dissolved in it (naphthalene or acetate) or in the form of an aqueous solution (for sulfates or chlorides) [4].

The use of Magnesium oxide additives is one of the important methods used to extend the life of the steel component of boiler tubes and turbine blades Gaseous fuels that use (residual fuel) because magnesium oxide has the ability to form vanadates) Stable ($Mg_3V_2O_8$) which remains solid at working temperature in steam boiler tubes and blades Gas turbines [18, 19].

$$3MgO + V_2O_5 \rightarrow Mg_3V_2O_8 \quad (1)$$

The compound ($Mg_3V_2O_8$) does not depend on the amount of (MgO) when the ratio (MgO: V_2O_5) is less than (1:3) and the reaction products contain ($MgO_3V_2O_5$) and an increase of (V_2O_5) when the ratio is less than (1:3) and an increase in (V_2O_5) and an increase of MgO (when the ratio exceeds 1:3).

The compound (V_2O_5: MgO) is affected by the appearance of (SO_3/SO_2) in the air from sulfur pollutants [16] As in the following chemical equation:

$$SO_2 + \rightarrow \frac{1}{2}O_2\ SO_3 \quad (2)$$

And when SO_3 appears sufficiently, MgO reacts with sulfur and turns into ($MgSO_4$):

$$MgO + SO_3 \rightarrow MgSO_4 \quad (3)$$

The compound ($MgSO_4$) can then be reacted with (V_2O_5) to form the magnesium disulfide and ($V_2O_5.2MgO$) fused to the surface of boiler tubes and turbine blades [20].

$$MgSO_4 + V_2O_8 \rightarrow 2MgO.V_2O_5 + SO_3 \quad (4)$$

Fluids cause erosion of the turbine wings and lead to a reduction in their rotation and thus efficiency over time, in addition to the corrosion of acidic liquids, which more affects the fuel combustion chamber (fuel saturators, fuel flow tubes, compressors) [21].

Figure 1. Corrosion in turbine blades

The sulfates (pollutants) that result from the use of fuel in engines interact with the material that makes up the engine equipment, especially the fuel injector. It works on corrosion, and this is what works on the rapid decomposition and corrosion of the metal [22] as Figure 1.

Corrosion is classified into two categories; type I Hot Corrosion Attack to Turbine Blade. This type of corrosion occurs in the turbine unit or boiler, which is one of the most dangerous types of corrosion. It is easy to know the occurrence of oxidation in the turbine unit, and it can be reduced by control it, because it includes first the interactions of metal - oxygen. As the temperature increases, the frequency of oxidation increases, and the occurrence of corrosion due to oxidation can be reduced by manufacturing protective layers of oxide (chromium, silicon, aluminum) and these elements are known for their resistance to the corrosion that occurs to metals and this Type I occurs at a temperature range of 730 to 950℃ [23, 24] as Figure 2.

Figure 2. Hot corrosion attack to turbine blade

Type II Hot Corrosion Attack to Turbine Blade Shank. This type of hot corrosion is one of the forms of rapid oxidation that occurs due to the chemical reaction between the components of the metal substance and the salts that are deposited on the surfaces of metals. Where this type of corrosion consists of several complex steps of a chemical reaction, which makes it difficult to know this type of corrosion, which is sodium sulfate as a basic element for this sediment and the severity of the corrosion increases with the increase of pollutants (sodium, potassium, vanadium, chlorine, sulfur, fluorine, lead) and this Type II occurs at a temperature range of 550 to 730℃ [22, 25].

3.2 Mechanism of action of corrosion inhibitors

The development of rust on a metal surface is an electrochemical phenomenon that occurs due to the reaction of water and oxygen with the metal [26, 27]. This happens in the following three steps (Figure 3):

1. Oxidation of metal
2. Reduction reaction
3. Charge transfer from anode to cathode.

Heavy fuel contains relatively large amounts of vanadium, sodium and sulfur The combustion of which leads to the formation of most of the compounds of sodium sulfate and vanadium oxides, which when the temperature of the boiler tubes and turbines rises during their work, a reaction occurs for these materials and a series of compounds,(V_2O_5, Na_2O, SO_3) is formed where their melting points are relatively low and settle on the surfaces of turbines and boilers, This leads to the gradual dissolution of the components that make up the turbines and boilers, causing corrosion, which requires replacing them as soon as possible as in Figure 4.

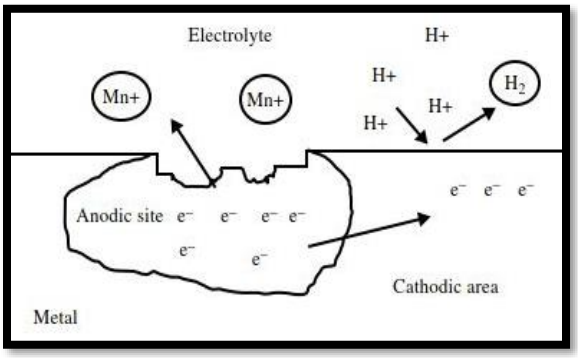

Figure 3. Electrochemical corrosion of metals

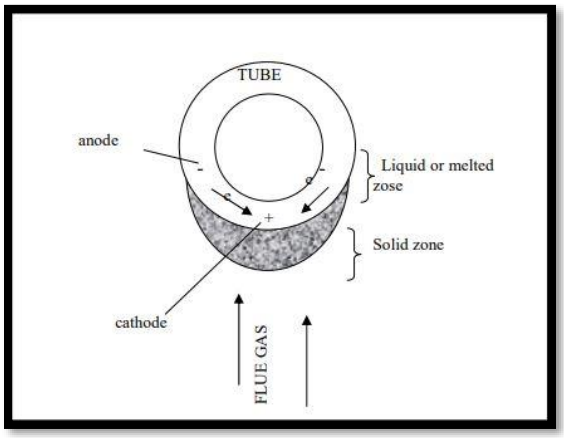

Figure 4. Hot corrosion [28]

Various methods have been used to prevent this corrosion known as hot ash Corrosion, including the method of using additives (for fuels, which work to form vanadates). It is stable at high melting points rather than the low-melting vanadium compounds (that usually appear) and this prevents the formation of the liquid phase at the operating temperature of the turbines and boiler [29, 30].

Shifler [31] explained the effect of some Additives such as calcium, magnesium and zinc compounds that work to form stable vanadate (3Metal Oxide: 1Vanadium Pentoxide).

Magnesium compound is the most important additive used to reduce the occurrence of corrosion by hot ash because it prevents Formation of sodium vanadate and vanadium sulfate with low melting points by forming magnesium vanadate (MgxVyOz), which melts at temperatures higher than 1000℃ (that is, it raises the melting point Precipitations that range from 680℃ (for the compound vanadium pentoxide) to 1100℃ (for the compound) V_2O_5.MgO (so it is highly effective [7, 9].

That control corrosion Hot because of the use of poor or residual fuel depends on the formation of compounds containing solid vanadium and the formation of These compounds are affected by the appearance of (SO_3) [32].

The researcher Meier et al. [22] concluded that when injecting magnesium particles (as additives) It can generate several benefits for operating boilers, including reducing combustion radiation to about 80%, as well as reducing emissions Total particulate matter by 60% and metal corrosion reduction by 50%.

One of the unnoticed problems when adding magnesium compounds is that they usually cause an increase in pollutants, sediment and increased melting point of the compounds formed.

Researchers such as Kumar et al. [33] (found through his research that the addition of magnesium compounds It improves combustion conditions and reduces the ignition time delay, as well as reducing sulfur trioxide (Sulphar) in the gas vapor to less than (5ppm).

Researchers Chernova [3] (they studied the effect of adding MgO on corrosion at degrees The high temperature, where they found that the (weight loss causing hot corrosion) to decrease when adding (MgO) to about a degree Equal to corrosion when kerosene is used as fuel in the combustion chambers of steam boilers.

3.3 Solutions of chemical problems

It is very difficult to prevent a certain degree of interaction between a mineral composition and high temperature gases, so the common term "Prevent" is not fully applicable, but rather is intended to reduce the degree of damage and reduce the degree of interaction and friction. There are many ways in which damage can be reduced, including:

1- Changing environmental conditions.

2- Change the material.

There are three basic ways of environmental conditions, they can be applied to reduce corrosion problems and these are:

a. fuel wash

b. Addition of corrosion inhibitors

c- Changing the combustion state to reduce the reaction [34].

3.4 metals used to control high temperature corrosion by fuel additives

To control the corrosion caused by high temperatures, a special formula for fuel pumps is made, consisting of magnesium, silicon and chromium. This formula consists mainly of magnesium that resists vanadic by mixing with V_2O_5 at an appropriate Mg /V treatment ratio, magnesium ortho vanadate [$3MgO.V_2O_5$] It forms as ash when it reaches a high melting point of 1243 degrees. In addition, chromium is used to resist corrosion by sulfur, and it also reduces ash pollution by forming compounds that volatilize through turbines. Silicon is also used as an anti-corrosion reinforcement and ash disintegrator [35, 36].

Iron is added in the form of carboxylic acid salts in fuel oil, as it improves combustion. In addition, iron oxide is used to reduce smoke pollution at 50ppm [37].

4. EMISSIONS OF HEAVY FUEL OIL

International reports indicate that the demand for energy will increase by about 1.6 percent by the year 2030. This was confirmed by the International Energy Agency (Figure 5), which necessitates the search for renewable alternatives to energy sources and the improvement and treatment of some energy sources, including fossil fuels, whose derivatives are used in many production processes such as the use of fuel oil in electric power stations, whose use results in pollutants that are harmful to the mineral materials that make up the turbines and the environment surrounding [38].

There is an urgent need to use renewable energy, including reducing harmful emissions such as carbon dioxide, nitrogen oxides and gases.

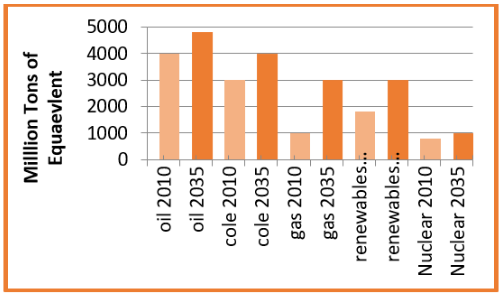

Figure 5. World primary energy demand by fuel [39]

Today, many researches focus on biomass and how to obtain fuel from it for the various purposes of life [40].

Gaseous pollutants are produced due to the incomplete combustion of the fuel, as in the case of complete combustion all carbon is converted into carbon dioxide gas and all sulfur is converted into sulfur dioxide gas. On the contrary, when combustion is incomplete, it will produce Pollutants, which are the main cause of reduced combustion due to lack or absence of oxygen [41].

4.1 Gas turbine emissions and health impact

This section can be divided into two parts:

A- Gas turbine emissions

Emissions from gas turbines are considered low when compared to gas emissions carbon dioxide, in addition, gas-based turbines do not operate in idle mode, unlike air-gas turbines, where CO_2 and NO_X emissions are very high in idle mode [42]. Table 3 indicates the most important gases emitted from the exhaust of gas turbines and what are their sources and effects on the environment.

Table 3. Emissions from fuel turbines [43]

The most important gases	Typical Concentration (96 volume)	Emission source
(N_2)	66 - 72	Inlet Air
(O_2)	12-18	Inlet Air
(CO_2)	1.5	Oxidation of Fuel Carbon
(H_2o)	1.5	Oxidation of Fuel Hydrogen
Minor Pollutants	Typical Concentration (PPMV)	Emission source
(NO)	20 - 220	Oxidation of Atmosphere Nitrogen
(NO_2)	2 - 20	Oxidation of Fuel-Bound Organic Nitrogen
(CO)	5- 330	Incomplete Oxidation of Fuel Carbon
(SO_2)	Trace-100	Oxidation of Fuel-Bound Organic Sulphur
(SO_3)	Trace - 4	Oxidation of Fuel-Bound Organic Sulphur
Unburned Hydrocarbons (UHC)	5- 330	Incomplete Oxidation of Fuel or Intermediates
Particulate Matter Smoke	Trace - 25	Incomplete Oxidation of Fuel or Intermediates, Fuel Ash, Inlet Ingestion

B- The most prominent gas turbine emissions

Exhaust emissions include CO_2, NOx, H_2O, and O_2 gases, where the proportion of these gases is estimated in percentages, and the only CO_2 gas responsible for the greenhouse effect is among those gases [44].

It is possible to calculate the proportions of these gases if the fuel components are known and that they are products of complete combustion. With regard to the second category, it is considered the most dangerous to human health, such as (PM) aerosols, unburned hydrocarbons and carbon monoxide gas.

Dioxide gas occupies the largest proportion of these emissions, estimated at 40% [44]. In the end, carbon dioxide is the product of combustion of fuel, and it can only be eliminated by improving the fuel or using a renewable alternative fuel [44, 45].

With the increasing global economic crisis and the exacerbation of global warming, there is an urgent need to find alternative sources of energy and less pollution [46].

Carbon monoxide gas obstructs the transport of oxygen in the blood through the formation of a complex of carboxy hemoglobin, which increases the heart's pumping of blood, which may result in problems that impede the work of the heart [47, 48].

Despite the harmful effects on health caused by hydrocarbons (UHCs), they participate in the formation of ozone, which protects the earth from harmful cosmic rays and One of the harmful emissions from gas turbines is nitrogen oxides [49].

5. CONCLUSION

The current review dedicated to investigate the effect of heavy fuel utilization in operating gas turbine on the power plant performance. The following conclusion can be addressed;

- The most prominent impact of the use of heavy fuel on the performance of power plants is the corrosion that affects the turbines and the metal parts that make up them, because heavy fuel contains vanadium and sulfur, and when the fuel burns, it results in the oxides of these elements (impurities) that lead over time to the corrosion of metal pieces and thus affect the overall plant efficiency.
- Corrosion occurs in the most important part of the turbines, which is the turbine wings, which are responsible for rotation and thus power generation, as acid fluids (pollutants) are deposited on them and lead to damage over time.
- There are several methods to prevent corrosion, including adding chemical compounds to the fuel before burning it in specific proportions, such as adding magnesium in the amount of 3:1 vanadium), which results in a stable compound.
- It is possible to add magnesium, silicon and chromium to heavy fuels, as magnesium mainly resists vanadic by mixing with V2O5, and chromium is used to resist sulfur corrosion, and it reduces ash pollution by forming compounds that volatilize through turbines. In addition, silicon is used as an anti-corrosion and ash disintegrator. Iron is added in the form of carboxylic acid salts in fuel oil, as it improves combustion. Additionally, iron oxide is used to reduce smoke pollution at 50ppm.
- The use of heavy fuels results in harmful emissions such as nitrogen oxides, carbon dioxide and other compounds that contribute to global warming and climate change, so it is necessary to go to alternative sources of fuel in the future that do not affect the environment.

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