

The Effect of Fuel Emulsion on Fuel Saving in Fire Tube Boilers of Tartous Company for Cement and Construction Materials

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Abstract: In this work, the combustion of heavy oil and its emulsions with water, in the fire-tube boilers, was investigated in experiments on an industrial scale. The performance of the fire-tube boilers, used in Tartous company for cement and construction materials, was studied when they were employed to be operated with heavy fuel oil (HFO) and with the water phase of emulsified heavy oil containing 8 vol. % water and 92 vol. % heavy fuel oil (HFO). The emulsified water/heavy fuel oil (W/HFO) with 8 vol. % of water content showed no separation and contained the smallest and most homogeneous water-in-HFO (W/HFO) droplets after stability tests. Four boilers, each with 8 ton h⁻¹ steam capacity, have been operated for 4 months with a regular heavy fuel oil HFO and W/HFO. It has been found that the micro-explosion, observed in W/HFO, improved the boiler efficiency and reduced the fuel consumption by 12.99%.

Keywords: Water, heavy fuel oil, W/HFO emulsion, fuel saving, experiment.

1. INTRODUCTION

A large part (57%) of all greenhouse gas emissions (known as greenhouse gases) is from the combustion of petroleum fuels used in industry and transportation [1]. These emissions are not only harmful to the environment, they are also harmful to human health, causing major lung diseases, cancer, asthma, heart issues and other fatal diseases. Hence the interest of scientists all over the world is in finding solutions to these problems. Currently, studies focus on using energy efficient fuels and reducing greenhouse gas emissions. One of the most popular fuels is emulsified fuel.

Emulsions are defined as a mixture of two or more immiscible liquids, one of them is dispersed precisely and homogeneously in the form of droplets (scatter phase) within the other liquid (continuous phase) [2]. The theory of water emulsion in fuel was developed in 1901 by the scientist Rudolf W. Gunnremans, and was experimentally verified in 1931 by the scientist Joseph Vance by modifying the mixing method and the amount of water added. Emulsified fuel has been used widely in the world. It is very important to stabilize the emulsion in the fuel for a long period of time. When using the emulsion, the improvement of the combustion yield is due to the phenomenon of micro explosion, and this phenomenon has a big impact on improving the combustion efficiency of emulsified fuel and low the emission of gases. This phenomenon was discovered for the first time by Ivanov and Nevedov in 1965 [3], where they found that the droplets suspended in the

emulsion of water in diesel were subject to explosion during combustion, and suggested that this phenomenon be called the phenomenon of micro explosion. Later on, this phenomenon received great attention among researchers to be studied in details.

There are a variety of interpretations to describe this phenomenon, but each of them reflects the same meaning [4]. Where the micro explosion was defined as the second division of the spray injected from the emulsion due to the evaporation of the water inside the emulsion drops [5]. More precisely, water droplets fall into the emulsified fuel. When the emulsified fuel is injected into a high-temperature environment, such as the combustion chamber, the heat is transferred to the surface of the emulsion drop, and the velocity of heat spreading to the liquid is limited, allowing the fuel drop to keep the water droplets inside. When the water temperature reaches the maximum heating temperature, a rapid explosion of water droplets occurs, which causes the entire fuel drop to expand and burst, splitting into several smaller drops [6]. As a result, more surface area of the fuel droplets is exposed to the air, which leads to an improvement in the air mixing process with the fuel, which increases the combustion efficiency. The companies working in the field of emulsion fuel production began to spread rapidly around the world starting in the late seventies of the last century, knowing that the research that focuses on this field occupies a good place between the modern and very recent scientific literature [7, 8, 9].

Numerous studies have demonstrated the possibility of reducing harmful gas emissions from power plants by controlling business patterns. The maximum yield of combustion in boilers must be secured from an economic and environmental point of

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view for the use of fuel in boilers. When taking into account the scientific reports written by specialists in the industrial boilers, it becomes clear that the most influencing factors on harmful gas emissions from power plants operating on the water/heavy fuel oil (W/HFO) emulsions are the moisture content and the increased air rate [10,11].

It has been shown through the mathematical modeling of the thermal boilers employment on W/HFO emulsions [12] that, the optimum values of emulsification ratio and excess air rate corresponding to the minimum values of harmful gas emissions from boiler chimneys are: i) 14-15% emulsification ratio and 1.05-1.1 excess air in relation to nitrogen oxide emissions; ii) 12-14% emulsification and 1.15-1.2 excess air in relation to carbon monoxide emissions; and iii) 11-13% emulsification rate and 1.15-1.2 excess air in relation to emissions of solid suspensions. Numerous studies have shown that emulsification of fuel with water leads to a reduction in greenhouse gas emissions such as nitrogen oxides and solid suspensions (see for example [13]).

Heavy fuel oil is one of the most commonly used petroleum fuels in boilers, although it is associated with a high level of pollutants. Emulsification is a developed technique to enhance fuel efficiency and reduce regulated pollution emissions. The use of emulsion water-fuel in thermal boilers does not require special equipment and modifications in the combustion, which makes the emulsion the cheapest possible way to save fuel and reduce emissions.

Water-in-oil (W/O) emulsification has been used as an alternative fuel technology to achieve more complete combustion and less pollutant emissions [5]. Micro explosion phenomenon is the major mechanism at work in emulsified fuels. The water phase is first dispersed uniformly by external forces, such as mechanical stirring or ultra-sonication. The specific surfactant is then added into the mixture during the emulsification process to stabilize the W/O droplets.

For W/HFO emulsion, the specific surfactant is not required [13]. In the beginning of the combustion process, the water droplets wrapped in oil are heated and transformed into water vapor. Furthermore, the vapor which has a volume about 1000 times that of the liquid water explodes through the surrounding oil and separates the W/HFO droplets into much smaller droplets that increase the total contact area with the air. Thus, the combustion efficiency is enhanced, and CO, HC, and PM emissions are further reduced at the same

time [14]. In addition, the water vapor could react with CO by water-shift reaction ($\text{CO} + \text{H}_2\text{O} = \text{CO}_2 + \text{H}_2$) to reduce the CO emissions and form hydrogen (H_2). Nevertheless, using emulsified fuel could decrease the temperature of metal units and increase the thermal load of a device [15, 16]. The water emulsified heavy fuel-oil (W/HFO) technique thus requires further investigation with regard to use in the industrial boilers.

The stability and W/O droplet size of the emulsion affects the strength of the micro explosions. The fuel, water content, density, dispersed phase fraction, surfactant, and dispersion technique were all optimized for stable emulsion in previous studies (see, for example, [17]); however, the high water fractions of W/HFO decreased the fuel economy in those earlier works, because the high latent heat of water consumed more enthalpy when the fuel droplet was heated at the beginning of combustion. Chen showed a breakthrough of 14% boiler efficiency improvement by using oily wastewater emulsified with heavy fuel-oil in 2008 [18]. Very few studies focus on the content and concentration of the dispersed phase of an emulsion.

According to Tran and Ghojel [19], and Debnath *et al.* [20], the combustion of a water-fuel emulsion in thermal boilers is characterized by the ability to take advantage of the difference in the volatilization of its two components. When the emulsion droplet is heated by radiation and by convection, its temperature rises and the temperature of its aqueous component becomes higher than the boiling water temperature, which causes it to rapidly inflate, forming gas bubbles that in turn explode and detonate with the surrounding layer of fuel, which leads to the formation of small droplets of fuel, which greatly increases the specific surface of the droplets. This improves the fuel mixing with air, increases the combustion yield, reduces harmful gas emissions and raises the total boiler return value [21]. The process of micro-explosion resulting from the presence of water in the emulsion also affects the physics and chemical kinetics of combustion [22]. On the other hand, the presence of water in the emulsion reduces the flame temperature and changes the chemical components of the reactants, which increases the concentration of OH roots that control the rate of formation of NO_x and the oxidation of solid suspensions and reduce their concentration in the rich areas of the combustion chamber [22].

The savings in the amount of the used HFO in the fire tube boilers could be achieved by improving the efficiency of the fire tube boilers by:

- Increasing the calorific value of the used fuel.
- Improving the combustion process.
- Improving the heat exchange within the boiler.

Although the calorific value of the emulsified fuel decreases with increasing mixing rate with water [23], the amount of conventional fuel, which is in the emulsion, required to produce the same amount of heat produced from pure fuel is less than the amount of pure fuel by a percentage that will be determined in this work when the fire tube boilers are employed at 8% of water content in the W/HFO emulsion. This is a ratio that directly falls in the efficiency improvement rate of the used boilers. Therefore, the primary goal of the present work is to investigate the performance of the fire-tube boilers at $W_{0.08}/HFO_{0.92}$ emulsion.

2. MATERIALS

2.1. Tartous Company for Cement and Construction Materials

The Tartous Company for cement and construction materials is located about 1.5 km from the beach of Mediterranean sea 10 km North of Tartous city. The power station of this company consists of 5 fire tube boilers; one of them (boiler No. 3) is in the maintenance. The mentioned power station is used to heat HFO before feeding the cement kilns. Each of the working boilers is of 8 ton h^{-1} steam capacity. The power station has been operated for 4 months with a regular heavy fuel oil HFO and W/HFO. A mini city for the employers of the company is located west of the company by 750 m approximately. Thus, the ecological

effect of the company on the surrounding area is considered as a pro factor for the project of water/HFO emulsion.

2.2. Heavy Fuel Oil Characterization

Samples from the used HFO were studied periodically during the experiment. The ASTM D5854 standard procedure [24] was followed for collecting the crude HFO samples. Following [24] and [25] the free water was separated from each sample by decanting over one-hour period before any characterization step. Then, the sample is dehydrated by adding 250 μ l of commercial demulsifier and centrifuged at 2000 rpm for 20 min at 60 °C. The water content in the oil was quantified by a standardized method ASTM D4377.

The dehydrated HFO was characterized according to ASTM D1298 for the specific gravity, ASTM D1552 for sulphur content, ASTM D92 for flash point, ASTM D97 for pour point, ASTM D445 for kinematic viscosity, ASTM D482 for ash content and ASTM D240 for the heat of combustion. Asphaltenes and vanadium contents were characterized according to UOP614 and UOP391 respectively. The results of characterization of a HFO sample are given in Table 1.

The physicochemical properties of the W/HFO emulsion samples were measured also according to ASTM and UOP standards. The water content of W/HFO emulsion was measured and found to be 8%. The net calorific value was measured and found to be 36.217 MJ/kg.

In the case of distilled water-HFO emulsified samples it was found that, the air bubbles were not

Table 1: The Chemical-Physical Properties of a HFO Sample

Property	Unit	Value	Method
Density at 15.56 °C	kg/m ³	978.7	ASTM D1298
Flash point	°C	134.0	ASTM D92
Pour point	°C	1.0	ASTM D97
Kinematic Viscosity at 98.89 °C	mm ² /s	40.00	ASTM D445
Water and sediments	%v	0.2	ASTM D96
Asphaltenes	% wt	3.00	UOP 614
Sulphur	% wt	4.77	ASTM D1552
Vanadium	ppm	128	UOP 391
Water by distillation	%v	0.5	ASTM D95
Ash	% wt	0.032	ASTM D 482
Net calorific value	MJ/kg	39.348	ASTM D240

observed and the emulsions were stable over a period of several months, which was judged by visual examination at room conditions. The distribution of the water droplets in the HFO were monitored several times within the stabilization period observing a dispersed homogeneous phase with water droplets of maximum diameter of approximately $5\mu\text{m}$ for all samples.

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

In order to determine the effect of fuel on each of the used boilers, the combustion yield E_f (%), boiler efficiency η (%), the excess air ratio λ (%), the temperature of the gas emissions from the chimney T_f ($^{\circ}\text{C}$), the ambient temperature T_a ($^{\circ}\text{C}$) and the concentration of each of the emitted gases (oxygen O_2 ; carbon monoxide CO ; carbon dioxide CO_2 ; nitrogen oxides: NO , NO_2 and NO_x ; hydrogen H_2 ; sulphur dioxide SO_2 ; and H_2S) were measured using Testo 350XL (see Figure 1). A flow meter, see Figure 2, was also installed to measure the amount of fuel used during the testing period, allowing these quantities to be measured and the average hourly average rate of fuel consumption calculated. As the boilers showed similar behaviour approximately the presented results will be related to the 5th one. The obtained results related to E_f (%), η (%), λ (%), T ($^{\circ}\text{C}$) and T_a ($^{\circ}\text{C}$) are given in Table 2 while the results related to gas emission concentration are given in Table 3. The obtained energy saving is given in Table 4.



Figure 1: Testo 350XL sensor in employment.

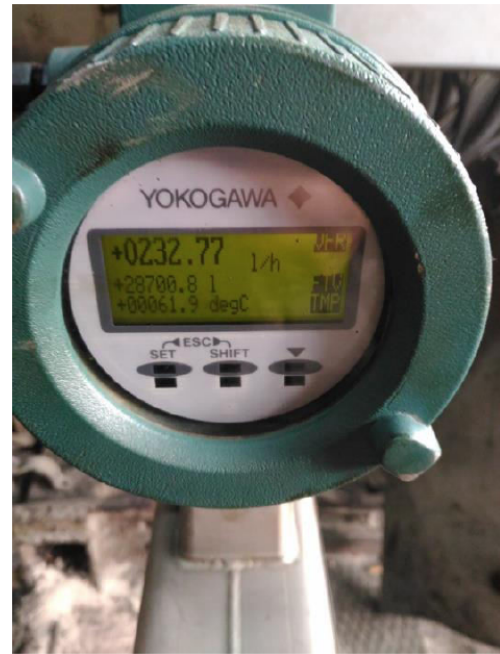


Figure 2: The used flow meter.

It can be seen from Table 2 that the use of W/HFO emulsion leads to a little improvement in the combustion yield E_f (%) and boiler efficiency η while the emitted from the chimney gas temperature decreases by 4.62%. Moreover, the provided measured results in Table 3 clearly demonstrate the amelioration of gas emission when the W/HFO emulsion is used in fire tube boiler.

Table 2: The Measured Characteristics of the 5th Boiler on HFO and W/HFO Emulsion

Fuel kind	E_f (%)	η (%)	T_a ($^{\circ}\text{C}$)	λ (%)	T_f ($^{\circ}\text{C}$)
HFO	94.33	89.15	34.04	35.08	137.08
W/HFO	94.56	89.35	34.11	37.86	130.75

It can be seen from Table 4 that the use of W/HFO emulsion decreases the consumption rate by 6.05%. When considering that the water content of the used W/HFO emulsion is 8%, the required consumption rate of the HFO for obtaining the consumption rate of the W/HFO emulsion is $237.04 \times 0.92 = 218.08$ l/h. This means that the use of the W/HFO emulsion of 8% water content leads to a saving rate of 13.56%. The obtained results, in the presented work, are in a good agreement with those of [26].

4. CONCLUSIONS

Analysis of the obtained results allows the following conclusions:

Table 3: The Measured Gas Emission from the Chimney of the 5th Boiler

Fuel kind	O ₂ (%)	CO (ppm)	CO ₂ (%)	NO (ppm)	SO ₂ (ppm)	H ₂ (ppm)
HFO	5.33	11.13	11.79	148.25	1955.38	4.88
W/HFO	5.74	10.5	11.48	145.46	1876.63	2.5

Table 4: The Consumption Rate

Fuel kind	Initial reading (l)	Final reading (l)	Quantity (l)	Duration (h)	Consumption rate (l/h)
HFO	13737.64	16332	2594.36	10.28	252.30
W/HFO	1959.42	4638	2678.58	11.3	237.04

- The use of W/HFO emulsion with 8% of water content decreases the concentration of the emitted gases from the boiler chimney.
 - The use of W/HFO emulsion with 8% of water content improves the combustion process and the boiler efficiency.
 - The use of W/HFO emulsion with 8% of water content leads to a saving rate of 13.56% in HFO.
 - The use of W/HFO emulsion with 8% of water content decreases the maintenance periods significantly.
 - The use of W/HFO emulsion with 8% of water content on the cement kilns will be hopefully treated in the near future.
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