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Investigations on burning efficiency and exhaust emission of in-line type emulsified fuel system

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Abstract
In this research, the burning efficiency as well as exhaust emission of a new water-in-oil emulsified fuel system was studied. This emulsified system contains two core processes, the first one is to mix 97% water with 3% emulsifier by volume, and get the milk-like emulsified liquid, while the second one is to compound the milk-like emulsified liquid with heavy oil then obtain the emulsified fuel. In order to overcome the used demulsification problem during in reserve or in transport, this system was designed as a made and use in-line type. From the results of a series burning tests, the fuel saving can be over 8~15%. Also, from the comparison of decline for the heat value and total energy output of varies emulsified fuel, one can find that the water as the dispersed phase in the combustion process will leading a micro-explosion as well as the water gas effect, both can raise the combustion temperature and burning efficiency. By comparing the waste gas emission of different types of emulsified fuel, one can know that, the CO2 emission reduces approximately 14%, and NOx emission reduces above 46%, that means the reduction of the exhaust gas is truly effectively. From the exhaust temperature of tail pipe, the waste heat discharge also may reduce 27%, it is quite advantageous to the global warming as well as earth environmental protection.

Keywords: Emulsified fuel; Micro-explosion; In-line type; Waste gas emission; Waste heat discharge.

1. Introduction
Since middle of 20th century, the progressive developing of industry has great improved the life of human beings, but huge consumption of fossil energy also caused the crisis of energy deficiency and exhaustion. Moreover, the serious global warming which causes the ecological destruction as well as large-scale and fatal disaster is happening in the past ten years. In order to slow down the global warming of the Earth, and let whole of conditions of the environment could return in 1980’s standard, the developed countries in particular European countries, positive proposed some kind of feasible plans to solve the fast worsening crisis effectively.
Without doubt, the reduction of the greenhouse gas emissions will be able to attack the industrial development, but if the clean types of energy are used to substitute the fossil energy massively, and the more effective equipments are developed and utilized, it might give dual attention to the greenhouse gas emission and the industrial development. Besides it might also create a new business domain based on the green technology, and leading the advantageous to the overall industries. In recent years, the solar

energy, the wind power energy as well as the biomass energy are rapidly developed, but the related technology was still at the earlier stage, need to pay much more attention on it continuously.
There are two ways or directions to use the fossil energy more effectively, one is to improve the efficiency of burning facilities [1], especially for the used or the obsolete fuel-burning equipment, the other is joins the fuel oil with other material like water or biological solution and then emulsifies the compound The total quantity of emulsified fuel will increase, if the system to be possible to maintain the normal operation under the consumption of less emulsified fuel, and obtains the needs of heat value, then one has get into the purpose of saving energy [2-6].
Studying the technology of the emulsified fuel and its combustion efficiency has been long, recent years, the researchers from Japan and China have obtained some achievements [7, 8, 9]. At present, the industrial world commonly used three different processes to get the emulsified fuel, first kind is directly adding the chemical additives to the heavy oil, and then disturbing it. By this way, the reduction of fuel consumption is below 5%, after deducting the cost of the chemical additives, only 2~3% actually, the benefit is limited.
The second method is to use of homogeneous machines to homogenize heavy oil and break up the asphalt sludge which is easy to deposit. In addition, it can reduce the pipe and burner nozzle block as well as improve the mixture ratio of oil and air, that will conducive to have more favourable combustion and to improve the energy efficiency by 2 ~ 3%, the benefit is still limited.
The third method is adding the right amount of water and additives into heavy oil, and after proper mixing procedures, so that water molecules become the dispersed phase is surrounded by the oil molecules, the emulsified oil production is completed. The just finished emulsified fuel required to stand for 6 to 8 hours or even longer to increase its stability, otherwise the solution will apt to demulsify. Generally, the composition and amount of emulsifying additives are classified as confidential, there may be use hydrocarbons or hydrogen compounds composed of polymer composite materials with different ingredients and methods, most will receive 4 to 6% of the energy saving effect [10, 11], compared to the above two methods, which is clearly more cost-effective.

2. Materials and methods

By previous researcher's findings, the efficiency improving of emulsion fuel combustion is caused by the micro-explosion effect, which is a rapid and strong phase transition in fuel, water and emulsifying agent. When the oil compound has sprayed into the combustion chamber, the oil mists absorb a lot of heat in a very short period of time, and make water molecules from liquid into vapor. Phase change of water molecules in the rapid expansion of volume, leading to the oil particles produce secondary atomization microburst occurred, so that oil droplets become smaller, and the surface area of oil droplets mixed with air will increase, so as to achieve the effect of best combustion.

2.1 Materials

In this study, the # 6 heavy oil produced by Chinese Petroleum Company (CPC) is taken as the based fuel or say as the continuous phase, and the water is taken as the dispersed phase. The theoretical heating value of heavy oil is at about 10,000 ~ 10,500 Kcal / Kg, contains more sulfur and asphalt, if direct use as fuel, much more suspended particles and higher SOx, NOx and CO will emissions, which may cause air pollution and global warming issues. On the other hand, the heavy oil with higher viscosity need a considerable proportion of mixture with diesel and preheated to 90 ~ 110 ℃ in order to improve its liquidity, though it is not absolutely an ideal fuel, because of its high heat value and price relatively inexpensive, it is still widely used by the industry.

2.2 Equipment and process

Used process of producing the emulsified fuel need to put it aside after the completion by 6 to 8 hours in order to increase its stability, however in the process of storage or transportation, the fuel is quite possible to demulsify. In this study, the in-line type of emulsification system GFOP (Green Fuel Oil Processor) will be used as a solution. Figure 1 is the outlook of a GFOP system and Figure 2 is the floe chart. The process mainly is composed of 2 core steps, the first one is mixing 3% of emulsion catalyst and 97% of water in volume, and doing the homogenization process by homogenizer, the milky white emulsion with the same density and mobility of water is prepared for next step use, it is not necessary to add additional ingredients, and can be directly mixed with heavy oil for the second core process. The mixing ratio between heavy oil and milky emulsion can be from 10% to 30% in volume, if the ratio is too low, it will be lack of economic attraction, on the other hand, if the ratio is too high, the total heat value of the fuel can be too low and can not make it possible to maintain normal operation of the boiler for minimum requirements.

Figure 1. Outlook of a GFOP system

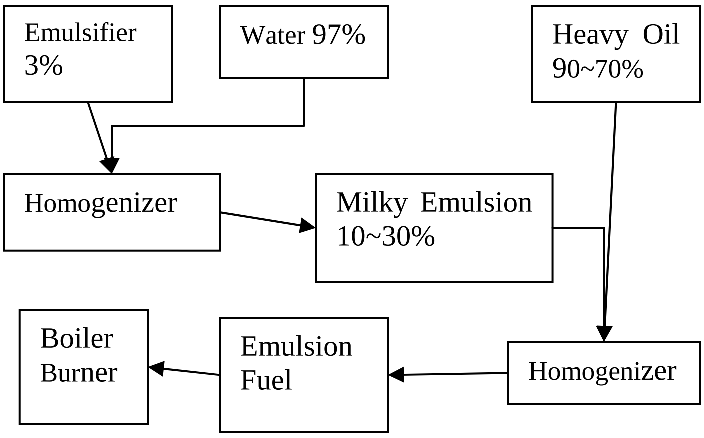

Figure 2. Flow chart of a GFOP system

2.3 Experimental technique and procedures

In this study, CPC # 6 heavy oil is taken as the based oil for preparing the three different components of the emulsified fuel, and labelled as GFO-1, GFO-2 and GFO-3. Experimental tests also will contain the based oil GFO-0 as a comparison, the proportion of the ingredients for those types of emulsified fuel are listed in Table 1.

Table 1. Combinations of different kinds of fuel

Items	#6 H/ O[%]	Water[%]	Emulsifier[%]	C / H by ASTM D5291
GFO-0	100.0	0.0	0.0	C86.61% / H12.28%
GFO-1	86.5	12.8	0.7	C83.15% / H12.02%
GFO-2	73.0	25.7	1.3	C72.85% / H12.07%
GFO-3	68.0	30.0	2.0	C61.22% / H11.92%

The combustion test of fuel supply rate, preheat conditions, combustion chamber pressure and temperature as well as environmental conditions are listed in Table 2. Owing to do the professional test for this study, the tests are commissioned in standard combustion laboratory of National Cheng Kung University in Taiwan. In order to obtain more reliable data, the furnace was preheated at first 60 minutes, then did the combustion test and lasted for 180 minutes.

Table 2. Conditions of different kinds of fuel for burning test

Items	Fuel preheat[^oC]	Fuel.sup.[L/hr]	Air sup.[m^3/hr]	Cham. P[Pa]	Cham. preheat[^oC]
GFO-0	80	20	170	-100	1140
GFO-1	80	20	145	-100	1140
GFO-2	80	20	135	-100	1140
GFO-3	80	20	110	-100	1140

3. Results and discussions

In this study, four different types of fuel as mentioned above are used to do the test separately, including temperature, air supply, burning efficiency, total heat value as well as emissions generated by combustion such as CO, CO_2, NOx and SOx are measured to be as a discussion basis. The results are shown in the following tables.

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3.1 Comparison of air supply and flame temperature

Table 3 shows the different preheating fuel by burner in the main chamber after the completion of combustion, 180 minutes from start to measure the average temperature of furnace chamber, GFO-1 with the content of 86.5% heavy oil, but its temperature maintain rate is 99% , it means that the efficiency is about 12.5%. GFO-2 of the heavy oil content of 73.0% with its temperature maintain rate of 93% means the efficiency is amazingly up to 20%. The GFO-3 of only 68.0% heavy oil content, while the average temperature was maintained in 88%, the efficiency is also up to 20%. Without counting the cost of equipments, after deducting of catalyst and processing costs, the actual saving benefits should be up to 8 ~ 15% or even more.

Table 3. Flame temperature and air supply by using different kinds of fuel

Items	Fuel com.[L/ hr].	Air sup.[m^3/hr]	Heavy oil cont[L].	Cham.T.[^{o}C]	Efficient[%]
GFO-0	20	220 (100%)	20.0(100%)	1118 (100%)	0.0
GFO-1	20	195 (89%)	17.3(86.5%)	1102 (99%)	12.5
GFO-2	20	185 (84%)	14.6(73%)	1045 (93%)	20.0
GFO-3	20	160 (73%)	13.6(68%)	991 (89%)	20.0

On Table 3, the fuel supplied rates are fixed on 20 litters per hour. And the air supply is adjusted to keep the furnance chamber in optimum combustion. From the results of series tests, one can find that the less heavy oil content the lower volume combustion air required. Also, by inspecting the flame in the chamber, one can not find the unstable burning phenomena which was caused by the demulsification.

3.2 Comparison of combustion efficiency and total heat value

Table 4 shows the burning efficiency of different types of emulsified fuel by measuring the tail pipe temperature and calculating its heat loss. From the results, one can convert the data to burning efficiency. The results show that the burning efficiency of those three kinds of emulsified fuel is almost same with the GFO-0 and all around 85 ~ 87%, that means the burning efficiency have not much relationship with the proportion rate of heavy oil. In addition, as GFO-3, the heat value of emulsified fuel reduced to 70%, but the burning efficiency of it still able to maintain in 87%, it may reasonable infer that the contribution of extra energy is from the water-gas effect and the micro-explosion of water in oil.

Table 4. Burning efficiency and total heat value with using different kinds of fuel

Items	Heavy oil com. [L / hr]	Total heat value[Cal/g]	Equivalent H/V [%]	Efficiency[%]
GFO-0	20.0(100%)	10,627 (100%)	100	85
GFO-1	17.3(86.5%)	10,162 (96%)	111	86
GFO-2	14.6(73%)	8,941 (84%)	115	87
GFO-3	13.6(68%)	7,443 (70%)	103	87

In this study, the heat value of the test is determined by ASTM-D24. As the tests for these three types of emulsified fuel combustion, the GFO-1 with the heavy oil content of 86.5%, the heat value of it is 96%, the equivalent heat value is 111%. The GFO-2 with the heavy oil content of 73.0%, the heat value of it is 84%, the equivalent heat value is 115%. For the GFO-3 of the heavy oil content 68.0%, the heat value of it reduced to 70%, but the equivalent heat value is still keep on 103%. The difference of equivalent heat value for GFO-1and GFO-2 with GFO-0 are 11% and 15% respectively, but for GFO-3, it is very limited, only 3%, the reason is that, for high water contained of the emulsified fuel, the low combustion temperature cause the water-gas effect and micro-explosion effect a little bit diminished.

3.3 Comparison of emissions

Table 5 shows the comparisons of the exhaust gases, including carbon monoxide CO, carbon dioxide CO_2, residual oxygen O_2, nitrogen compounds NOx and sulfur compounds SOx, etc... The results show that very little of carbon monoxide CO exist, that is because of high chamber temperature and well adjustment of combustion conditions. As carbon dioxide CO_2 and nitrogen compounds NOx emissions decline in 3~ 14% and 10~ 46% relatively, the more water contained in emulsified fuel, the less emission generated. The results also show that residual oxygen O_2 and emissions of sulfur compounds SOx become higher, the former may be due to excessive air supply, and the latter could be with the higher sulfur content in catalyst and cause such adverse effects, air flow rate adjustment and the type of catalyst selection need be more cautious.

Table 5. Combination of exhausted gas

Items	CO [ppm]	O_2 [%]	CO_2 [%]	NOx [ppm]	SOx [ppm]
GFO-0	0	3.7	14.0(-0%)	389(-0%)	218(+0%)
GFO-1	0	4.0	13.5(-3%)	349(-10%)	240(+10%)
GFO-2	0	4.9	13.1(-6%)	289(-26%)	235(+8%)
GFO-3	0	7.1	12.0(-14%)	211(-46%)	223(+2%)

Another term which will pollute the environment is waste heat of combustion emissions, the greater the value of waste heat, the more harmful to the environment. Table 6 is the average temperature of emissions measuring from the exhaust pipe. The data obtained show that, the more water contained or lower heat value of the emulsified fuel, the less waist heat emission, a maximum decrease of 27% can be achieved, which is very good for environmental and ecological protection.

Table 6. Tail pipe temperature

Items	GFO-0	GFO-1	GFO-2	GFO-3
Tail pipe temp. [℃]	230 (0%)	205 (-11%)	198 (-14%)	165 (-27%)

4. Conclusions

In the time of energy absence and severe global warming, the more efficient use of energy is the only way to solve the problem. In this study, a new process as using in-line equipment for water in heavy oil emulsified fuel has been used. From the measuring data of chamber temperature, air supply, burning efficiency, total heat value as well as emissions generated by combustion, the following conclusions has been made. Firstly, the emulsified fuel produced by this in-line type can be a way to ensure its quality and stability, to reduce standing time and space, and completely exclude the risk of demulsification. Secondly, by comparing the temperature maintain rate of the combustion chamber, the actual energy efficiency can be up to 8 ~ 15%. Thirdly, the use of supply air for emulsified fuel can be reduce up to 27% so as to reduce the exhaust gas and waste heat emissions Fourthly, the use of emulsified fuel does not affect the system energy supply, thought the total heat value dwindled a bit, the micro-explosion of water in oil and water-gas effect has made up the heat output effectively. Fifthly, the use of emulsified fuel is significantly reducing greenhouse gas CO_2 up to 14% and NOx up to 46%, at the same time, the reduction of waste heat emission was 27%, those can effectively reduce the air pollution and the crisis generated by global worming.

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