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Acknowledgements

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ALTERNATIVE FUEL TEST STUDY OF AN DIESEL ENGINE FED BY SYNTHETIC FUEL DERIVED FROM WASTE BILGE OIL

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Key words: modulation of fuel stock, engine loading test, pollution emission.

ABSTRACT

In order to enhance engine efficiency and decrease pollution emission, the relative experiments with mixed fuels were involved in this paper. For example, the synthetic fuel derived from waste bilge oil was mixed with heavy oil or bio-diesel separately, in addition, the accelerant so as to increase the viscosity of mixed fuel and decrease pollutant emission was added to mixed fuel to promote engine combustion efficiency.

Firstly, various mixed fuels were sent to Refining & Manufacturing Research Institute of Chinese Petroleum Corp to detect the characteristics of heating value, flash point, volatility, viscosity and contents of nitrogen, chlorine & sulphur etc. The previous feasible tests of mixed fuel were performed by Lushan (brand name) small engine (3Hp) and the generated power output and hydraulic dynamometer detection for engine (full) load were experimented by Zhengyu (brand name) diesel engine. The test data was applied to evaluate the feasibility of the besting mixed fuel individually with the parameters of engine efficiency and pollutant emission.

I. INTRODUCTION

In recent years, the application of derived fuels from the waste have attracted great attention on the basis of factor changes, such as energy diversification, energy conservation, environmental protection and ecological protection etc.. In particular, the PGS (power generation system) technology resulted from diesel engine modification has deserved promotion rapidly. When the original diesel engine system has transferred into waste derived fuels, however, the system must adjust the parameters or hardware to fit the differences among heating value, volatility and combustibles of derived fuels. Let us take the PGS of internal combustion engine as an example. Besides the similar operating mechanism of gasoline engine and diesel engine such as admission, burning, exhaust, adjustment, lubrication and cooling systems, it has different fuels and ignition system. Therefore, the waste derived fuel will be applicable for the general internal combustion engine if we adjust or revise the mixer, ignition fuel injection angle, compression ratio. According to the property of applicable fuels, when the spark plug is used for ignition timing controlling, the compression ratio of the gasoline engine is 5-8. While the ignition point is controlled by injection timing, the ratio is 22-25.

In terms of engine system of gas burning system, though the gas features in its good permissibility and high compression ratio of 8.8, the gas compression is higher than that of petroleum while the gas heating is much lower than that of petroleum. Under the condition of mixed gas in same volume, the output horsepower of gas engine is little lower than that of fuel engine. Moreover, the operating mechanism of gas ignition explosion is slow when compared to that of petroleum, which requires the related parameter data of ignition angle and ignition timing on the basis of experiment.

Although the diesel engine could not avoid some disadvantages such as heavy shock, high level of noise, necessary cooling water in large amount etc., it still becomes the motive power that has drawn most attention since it is economical, reliable and cheap to maintain. Therefore, the diesel engine set is the best choice for synthetic fuels.

II. PURPOSE OF RESEARCH

As for the synthetic fuel derived from waste bilge oil, its low viscosity and high volatility are not suitable for diesel engine. Many studies have focused on lubrication property of mixture of heavy oil and synthetic fuel derived from waste bilge oil. This kind of mixed fuel has the same viscosity with that of diesel oil, which guarantees the smooth operating of engine. For a long time operation, however, the engine is not as stable as it was before. In this case, this research aims to solve the problem of engine operation for a long time and appropriate fuel mixture ratio to promote engine efficiency and decrease the pollution.

III. LITERATURE REVIEWS

The fuel heating value varies obviously with the differences of protoplast origins and processing procedure. In terms of

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protoplast, coal occupies the largest percentage for its storage. In recent years, many researches have focused on Integrated Gasification Combined Cycle (IGCC) [1, 6, 7, 8, 9] or the so-called Topping Cycle [3, 5]. The integral heat efficiency of the latter has reached 47% and helps to save the 20% power generation cost when compared to flue gas desulphurization equipments of traditional powdered coal burning.

It gasifies firstly coal of 70%-80% by fixed bed gasifier, and then performs gas transmission to power generation engine of gas turbine. Moreover, the survival cokes would be sent to cycling fluidized gas, which provides vapor for power generation. Literature [4] has pointed out that the sub product gas of steel refinery could be implicated as the power generation fuel.

Another large origin of low heating value fuel is Biomass fuel, such as rice husk, paper pulp, wood dust etc. that are considered as the waste difficulty to cope with.

Power generation application literature [2] of derived fuels has put forward many relevant explorations on many problems resulted from derived fuel combustion. There are conceptual definitions on gas composition, flame chemistry, limit of inflammability, burning rate, flame stabilization. To evaluate the inflammability limit of derived fuel by Le Chatelier method on the basis of provide data, we find that it occupies over 60.2% of heating value of tradition fuel, which comforts to a lot of derived fuels[2, 4]. When referring to combustion rate, it varies with component, dilution and pressure. With the help of equation evaluation in literature [2], we know that the variation range of burning rate is from 65 to 135 cm/sec when its equivalent ratio is 0.6-1.

Since the synthetic fuel content that has close relationship with adjustment parameter would affect the application efficiency and pollution emission, this paper sent synthetic fuel provided by applicant to Chinese Petroleum Corp. for content inspection. The following step is to analyze its influence on application efficiency and emission. Finally, test items, procedures and equipment specification will be defined, which is the testing conditions for diesel engines in the experimental lab and in the place of the Zhengyu Machinery Corporation that is manufacturer of diesel engines. What we shall perform next is to find out the relations among operation conditions, combustion efficiency and pollution emission so as to define the business application system specification and inspection standard. In order to satisfy the feasible test and application required by actual plant, a long term operation test for actual plant should be performed with the operators. After inspecting and confirming of the relevant result deserved from the experimental lab, items such as inspection item, method and key points of maintenance shall be covered.

IV. RESEARCH APPROACH

1. Property Analysis of Experimental Fuel

Synthetic fuel derived from waste bilge oil and mixed fuel were sent to Refining & Manufacturing Research Institute of Chinese Petroleum Corp. for inspecting the data that is related to engine combustion such as heating value, flashing point, volatility, viscosity and the relevant data of combustion pollution emission such as nitrogen, chlorine, sulfur contents etc.. According to the previous assessment on influence of system efficiency and pollution emission, the relevant testing item, equipment and procedure shall be studied and defined. Table 1 shows the comparison among inspection data of synthetic fuel, Heavy oil and diesel specification.

Table 1. Component analysis of synthetic fuel derived from waste bilge oil.

Value fuel item	synthetic fuel derived from waste bilge oil	diesel fuel	heavy oil
Density(g/cm^3)	0.8398	-	0.9513
flash point(ºC)	Room Temperature	60	98
pour point(ºC)	15	0	27 plus
Viscosity, Kin.(cSt) @ 50ºC (mm^2/s)	1.782	3.5	337.4
precipitate(%)	0.3	0.05	1.0
water content(%)	0.38	-	0.5
sulfur content(%)	0.12	0.05	0.5
Aromatic/carbon percentage(%)	0.25	-	-

2. The Establishment of Experimental Engine Testing Capacity

As there are various kinds of experimental fuels, the experiment adopts piecemeal approach. Firstly, we adopt Lushan small engine (3Hp) to perform pre-test of experimental fuels feasibility and basic pollution measurement. Secondly, we do load test by Zhenyu power generation equipment of CY-160RE diesel engine (16Hp). Finally, we do hydraulic dynamometer test by experimental oil in the place of Zhengyu Machinery Corporation to measure the engine efficiency and pollution emission under the condition of full load output so as to define the feasibility of experimental fuels.

3. The Experimental Test of Engine Operation

This research mainly aims to explore the feasibility to power generation equipment of diesel engine by synthetic fuel derived from waste bilge oil. The followings are the brief explanation for experimental items:

1) Test on Fuel Consumption Rate of Engine

In order to confirm the application of fuel exploration in this paper, we apply diesel fuel and various fuels to Lushan R165 small engine and Zhengyu CY-160RE power generation engine of diesel. The former is used in fuel feasibility test and the engine is under none-loaded condition. While the latter makes use of external air conditioner as load output and compares the influences of different fuels on engine by recording output power of power generator and fuel consumption. According to fuel heating value and fuel consumption rate, the engine efficiency of diesel engine could be calculated by output power of power generator/ (oil consumption rate*fuel heating value).

2) *Hydraulic Dynamometer Test (Zhengyu CY-160RE Diesel Engine)*

This test aims to evaluate the influences of applied fuels on engine operation (full load). In the place of the Zhengyu Machinery Corporation, we compare the influences of various fuels on engine torque and output power by hydraulic dynamometer in order to evaluate whether the tested fuels are feasible for the fuel stock of the engine.

This hydraulic dynamometer is applied to measure the torque and power of engine under specific rotate speed and load. In terms of engine capacity generated in the test, we make use of water absorption capacity resulted from pump and viscosity effect of a set of rotor and stator to free heat capacity. For most engines, this is the first choice for dynamometer. When output torque is 16 Hp, the highest rotate speed is 2500 rpm. In torque test, the max torque value is 6.7 kg-m, when the rotate speed decreases to 2400 rpm, however ,the horsepower is 2400×6.7 / 1000=16.08 Hp.

4. Pollutant Emission Test of Engine Combustion

This test aims to explore the influences of various fuels on the pollutants emission of engine combustion. The QUINTOX Combustion Analyzer, KM9006 is applied to measure the emission values of O_2, CO_2, CO, NO_x, and SO_x in flue gas, while the detector such as ROSECO Model 473B is applied to measure the participate emission. And, we analyze the Volatile Organic Compounds (VOCs) formed by synthetic fuel vapor derived from waste bilge oil and flue gas after engine combustion by Gas Chromatography (GC), which is used to evaluate the safeness of each kind of fuel. The experimental procedures are to measure emission values of various pollutants in the same time during the engine operation. In terms of VOCs inspection, we collect the gases by gas collection bag and entrust the Environment and Project Department of NCKU to do inspection on 17 VOCs by GC of HP GC 6890 model.

V. RESULTS AND DISCUSSION

1. Operation Test of the Engine

1) Analyses of the Fuel Consumption Rate

The fuel consumption rate for fuel stock of all mixed fuel is as much as 120% of that for diesel when the engine is under un-load conditions. Under the loading conditions, the atomization-evaporation mechanism can be enhanced by the increase of temperature in the cylinder of the engine, then, the efficiency of the engine can be promoted for all the mixed fuels. But, the efficiency of the engine can not be promoted for the mixture of all the mixed fuel and 0.5% additive even in loading conditions, because the mixed fuel is not suitable to diesel engine very much, the additive can not function efficiently. The fuel consumption rate for this mixture is also as much as 120% of that for diesel under both loading and unloading conditions as shown in Table 2.

2) Analyses of Output Torque and Power

The output torque & power were measured and analyzed by hydraulic dynamometer with Zhengyu brand model CY-160RE diesel engine. The mixed fuel is atomized into the cylinder of the engine by fuel nozzle in the high pressure condition at the end of the compression processes. The atomized fuel drops is vaporized to form flammable gases mixed with high- temperature and high-pressure air in the cylinder. This mechanism has close relationship with fuel volatility and the entrained air strength. But, the mixed fuel must be contained with high-viscosity oil, for example heavy oil, for atomization by the fuel nozzle. This requirement limits the effect of the volatility. Therefore, the output power increases but the output torque decreases with the increasing rotate speed of the engine shown in Figs. 1 and 2 because the atomized fuel drops is entrained into the cylinder and vaporized to gases, then, mixed with the high-temperature and high-pressure entrained air to form flammable gases by the strong air eddies as the rotate speed of the engine in increased. The entrained air eddies dominate this mixing mechanism.

Due to low volatility, the premixed combustible gas can not be formed completely in the cylinder of the engine for the waste bilge oil mixed with heavy oil and the rotate speed of the engine is lower. So, the output torque and generated power are both lower in this situation. The combustible gas is formed by the mechanism of strong inlet vortex with air as the rotate speed of the engine is higher. So, the generated power is almost the same with the mixed fuel (waste bilge oil and heavy oil) which compared with diesel as the rotate speed of the engine is higher.

Table 2. The correlation between fuel consumption rate and various fuel.

Rotation rate: 2350 rpm	R165 (unload)	CY-160RE (unload)	CY-160RE (6.7Hpload)
Diesel	100%	100%	100%
Mixed fuel	132.6%	120%	113%
Mixed fuel+0.5% additive	-	119.5%	120.5%
100% biodiesel	141.4%	-	123%
50% synthetic fuel+50% biodiesel	126.5%	-	118.3%

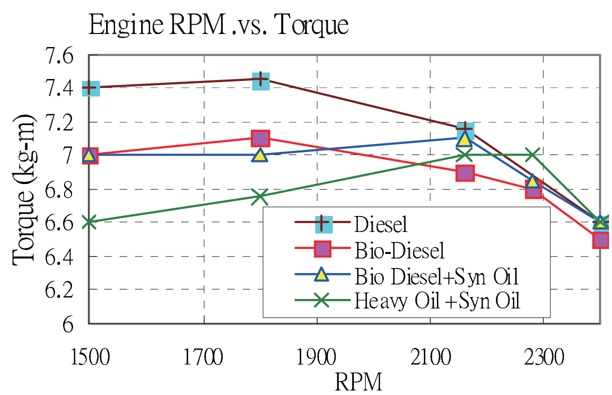


Fig. 1. The correlation between torque and rotation speed of the engine (CY-160RE).

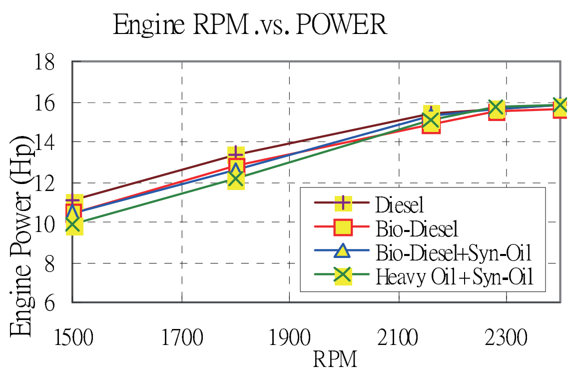


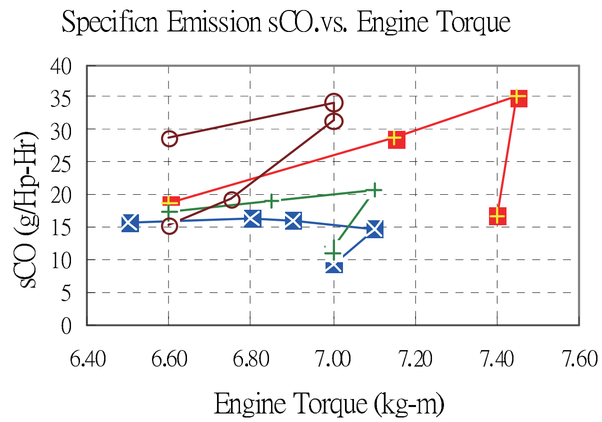
Fig. 2. The correlation between output power and rotation speed of the engine (CY-160RE).

2. Pollution Emission Test of Full-Load Engine

In the same rotate speed, the air quantity inhaled by engine is the same. In area of low rotate speed, oxygen in emission of diesel fuel burning is much lower than that in other fuels, which dedicates that more oxygen is required to satisfy the diesel fuel of high heating value. In addition, it also shows that relative perfect combustion could be gained by diesel fuel. If we defined that the specific CO emission is the sCO parameter for the quantity (gram) of CO emission per horse power hour (Hp*Hr) of the engine operation. The sCO can be analyzed for the correlation between the CO emission and engine power. For the fuel materials applied in this research, the max CO emission is generated in which the output torque reaches its climax shown in Fig. 3. Under such condition, the combustion is not so perfect. The high torque from diesel fuel combustion results in high CO emission value. The similar variation tendency of CO emission when oil contained bio-diesel is combusted. While the low CO emission value results from perfect combustion with high oxygen in it.

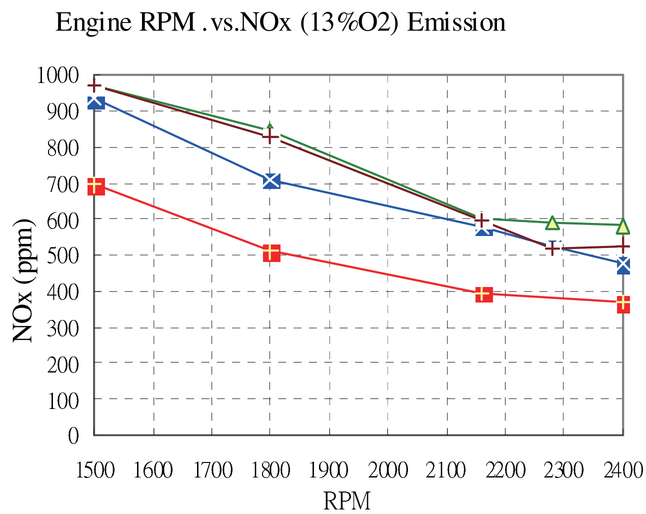
With the increase of engine rotate speed, the high-temp combustion gas in the cylinder of the engine is shortened, which results in the less chance of NO_x formation. Fig. 4 shows that NO_x emission value is decreased with the increase of engine rotate speed and NO_x emission reaches its lowest value when diesel fuel is adopted. NO_x emission value of synthetic fuel derived from waste bilge oil is 140% when compared to the diesel combustion. The engine combustion with diesel fuel is relative perfect, which results in low oxygen content and high admission temperature.

The formation of SO_x emission in flue gas of the engines is mainly influenced by the sulfur content in the fuel. Therefore, the SO_x emission occurs only for all the fuel contained sulfur content shown in Table 3. Because the synthetic fuel and mixed fuel are not suitable to diesel engine completely, the consumption rates are more for these alternative fuels shown in above section of the this research. And, the much completeness of combustion occurs under partial load condition relative to full load condition as shown in this paper, so the volume of flue gas is decreased in this condition that results in the higher SO_x emission value happens under partial load condition. As for the particulate emission, the higher particulate emission results from the increase of fuel consumption shown in Table 4 for all kind of fuel stock because more complete consumption performed in the cylinder of the engine due to the local high temperature areas formation in these situations.



red + :diesel; ×:bio-diesel; green + : synthetic fuel and biodiesel; ◇:mixed fuel

Fig. 3. The correlation between the CO emission and output toque of the engine (CY-160RE).



red + :diesel; ×:bio-diesel; △:synthetic fuel and biodiesel; brown + :mixed fuel

Fig. 4. The correlation between the NO_x emission and rotation speed of the engine.

3. Inspection of VOCs

This research does 17 kinds of VOCs inspection on synthetic fuel vapor derived from waste bilge oil by GC so as to ensure the safeness of applied oil. The result shows that vapor mainly includes chlorine and aromatic compounds. In 17 kinds of VOCs inspection items, the compounds that exceed 2000 ppm are acrylonitrile, dichloromethane, dichloroethane, cis-1, 2-dichlorethylene, carbon tetrachloride, trichloroethylene and toluene shown in Table 5. In terms of synthetic fuel derived from waste bilge oil (100% synthetic fuel derived from waste bilge oil +80% heavy oil, 50% synthetic fuel derived from waste bilge oil +50% biodiesel fuel), a large quantity of VOCs existed

Table 3. The correlation between SO_x emission and engine loading (CY-160RE: 2350 rpm).

SO_x (at O_2 13%)	15.8 Hp (full load)	6.7 Hp (partial load)	unload
Diesel	100%	114.7%	56.8%
100% biodiesel	-	-	-
50% synthetic fuel+50% biodisel	65%	69%	59%
Mixed fuel	142.7%	148.5%	80.6%

Table 4. Participate emission values of theCY-160RE engine: (2350 rpm).

	unload	6.7 Hp loading
diesel	100%	100%
Mixed fuel	259.8%	431.7%
Mixed fuel+0.5% additive	173.5%	193.2%
100% biodiesel	-	113.5%
50% synthetic fuel+50% biodiesl	-	93.2%

in volatile vapor is slashed into minim after the engine burning under the high-temp and high-pressure condition. The VOCs that exceed 2 ppm are acyloniti (7.48 ppm), carbon tetrachloride (9.2 ppm), toluene (2.6 ppm) and ethylbenzene (7.86 ppm) shown in Table 6.

VI. CONCLUSIONS

1. Operation Test of the Engine

The variation tendency is almost the same for the output torque and the rotate speed of engine with both bio-diesel and diesel as the fuel of the engine individually. Especially, the output torque with the bio-diesel fuel stock of the engine is smaller relatively. The maximum output torque was gotten in the area of high speed for all the mixed fuel with synthetic fuel derived from waste Bilge oil content. The reason results from the undesirable ignition quality caused by both medium boiling point 150% vaporization temperature and cetane value are lower for the synthetic fuel derived from waste bilge oil compared with that of diesel.

2. Analyses of Pollutant Emission after Combustion in the Engine

The max CO emission in the flue gas of the engine occurs as the output torque reaches its climax for all the mixed fuel applied in this paper. Under such situation, combustion is not complete in the engine. In detail, higher output torque is generated with diesel as the fuel of the engine, so, the CO emission in the flue gas of the engine is higher. As for bio-diesel as the fuel of the engine, the variation tendency of the CO emission in the flue gas of the engine is similar. But, all the CO emissions are lower along with the generated torque variations due to more complete combustion by the higher content of oxygen in bio-diesel. The CO emissions in the flue gas of the engine are highest for mixed fuel compare with both diesel and bio-diesel

Table 5. VOCs inspection on synthetic fuel vapor derived from waste bilge oil by Gas Chromatography.

Compounds	ppm
acrylonitrile	9819.06
dichloromethane	10093.63
1, 1-dichloroethane	5823.90
cis-1, 2-dichloroethane	20433.02
1, 1, 1-trichloroethane	531.80
bezene	556.50
carbontetrachloride	52181.20
trichloroethene	2318.47
ethylbenzene	ND
m-xylene	689.20
styrene	214.65
o-xylene	41.17
toluene	2273.86

Table 6. VOCs inspection on flue gas of the engine.

Compounds	50% synthetic fuel+50% biodisel ppm	Mixed fuel ppm
acrylonitrile	7.480	ND
cis-1, 2-dichloroethene	0.162	0.725
carbontetrachloride	5.886	9.200
o-xylene	1.146	ND
Toluene	ND	2.607
ethylbenzene	ND	7.867

due to the incomplete combustion with waste bilge oil and heavy oil contained in the mixed fuel.

The NO_x formation has less chance due to the high- temperature combustion gas stay in the cylinder of the engine shorter as the rotate speed of the engine is increased. So, the NO_x emission is decreased as the rotate speed of the engine is increased. The NO_x emission is lowest relatively for diesel as the fuel of the engine due to more complete combustion in engine that result in lower content of oxygen and high gas temperature in flue gas of the engine. The NO_x emission for synthetic Fuel derived from waste bilge oil. Heavy oil as the fuel of the engine is 140% more than that for diesel comparatively.

3. Analyses of VOCs Emission in Flue Gas of the Engine

The inherent VOCs can be destroyed almost by high- compression & high-temperature combustion conditions in the engine for all mixed fuel with synthetic fuel derived from waste Bilge oil, for example, 100% synthetic fuel derived from waste Bilge oil mixed with 80 heavy oil and 50% synthetic fuel derived from waste Bilge oil mixed with bio-diesel

The still existing compounds after combustion that their ratio of content exceed 2 ppm are acyloniti (7.48 ppm), carbon tetrachloride (9.2 ppm), toluene (2.6 ppm) and ethylbenzene (7.86 ppm).

4. Long-Time Engine Operation

In order to avoid the partial evaporation of fuel stock before entering the fuel pump that result in the block of normal fuel supply & in-efficiency of the fuel pump, then, cause the instability of the engine operation, the fuel stock must be pre-cooled before inlet especially for the long-time engine operation.

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