IMPACT OF FISCHER-TROPSCH DIESEL AND METHANOL BLENDED FUEL ON DIESEL ENGINE PERFORMANCE

by

Zhifei WU [a*], ***Tie WANG*** [a,b], ***Peng ZUO*** [a], **and *Muhammad Yousaf IQBAL*** [a]

[a] School of Mechanical and Vehicle Engineering,
Taiyuan University of Technology, Taiyuan, China
[b] Centre for Efficiency and Performance Engineering,
University of Huddersfield, Huddersfield, UK

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This paper discusses the impact of Fischer-Tropsch (F-T) diesel and methanol blended fuel, tentative engine was operated with fueled having F-T diesel and methanol blended fuel to compare the combustion and vibration characteristics. For this, 4100QBZL turbocharged diesel having parameters of F-T diesel fuel, FM5, FM10, FM15 methanol volume content was 5%, 10%, and 15%, respectively, have been selected for the experiment. Experimental studies have shown that when fueling with F-T diesel fuel, the ignition delay is shorter, the premixed combustion rate peak is lower, and vibration acceleration increases slightly than diesel fuel. Compared to the pure F-T diesel, the blended fuel has longer ignition delay period, higher the rate of pressure rise, combustion start point delayed, burning capacity increase, such as thermal efficiency is improved and vibration acceleration increased significantly.

Key words: *methanol, F-T diesel, turbocharged diesel, blended fuel, combustion, vibration*

Introduction

A significant quantity of energy gasoline and diesel is exerted all over the world perpetually and the basic part of this energy is supplied by fossil fuels. However, there is a known fact that these sources are not renewable and in near future these sources will be exhausted. The great significance to develop methanol from coal and F-T diesel oil (synthetic oil from coal) according to the present energy situation of rich coal and less oil in China.

The researcher studies about the application of F-T Diesel engine shows that [1-5], F-T diesel has higher cetane ratio, shorter ignition delay period and softer combustion, which can effectively reduce the vibration and noise of Diesel engine. The cetane number is a sign of the ignition delay of diesel fuel, and higher cetane numbers indicate that the fuel is easier to ignite. The contents of sulfur and aromatic hydrocarbon are very low and the emission of Diesel engine pollutants can be greatly reduced. However, the production cost of F-T diesel oil is on the high side. It is a waste of high quality resources that simply using F-T diesel oil to replace diesel oil in engine. We choose methanol as a blended fuel due to some reasons. The basic reasons are lower methanol prices, lower emissions, safer liquid fuels, and higher octane ratings, which can be used without changing the structure of the internal combustion engine.

* Corresponding author, e-mail: wuzhifei@tyut.edu.cn

The F-T diesel blended with methanol, a renewable oxygen-containing clean fuel, and exerts the characteristics of high quality combustion of F-T diesel, which increased fuel economy and expands the application range of F-T diesel applied to engines. The study of mixing combustion of F-T diesel and methanol is mainly focused on the way of injecting methanol into the intake port to ignite F-T diesel, which shows better combustion and emission performance [6]. There is little research on the mixed combustion of F-T and methanol [7]. In this paper, the impact of F-T diesel blended methanol fueling on the combustion and vibration characteristics of Diesel engines were investigated.

At the same time, the problem of vibration and noise of engine has attracted more and more attention. As the vibration signal of the engine is basically determined by the combustion state in the engine cylinder, so the combustion state of the cylinder can be evaluated and the fault diagnosis can be made using the vibrational signal.

Material method

The experimental test of the study were evaluated in Taiyuan University laboratories of the Vehicle Engineering Department. All experiment were performed on the direct injection medium Diesel engine test rig.

Testing fuel and physicochemical properties

The fuel used in the test included commercial $0^{\#}$ diesel, anhydrous methanol, and F-T diesel supplied by Lu'an Group. The F-T is base oil of the blended fuel, and using isooctane as solvent. Three kinds of blended fuels were named: FM5, FM10, FM15 (methanol volume content was 5%, 10%, and 15%). The comparison of the blended fuels physicochemical properties shown in tab. 1.

Table 1. Physicochemical properties of testing fuels

Parameter	$0^{\#}$ Diesel	FM5	FM10	FM15	F-T
Low heating value [MJkg^{-1}]	42.5	42.0	40.6	39.2	43.4
Density (20 °C) [kgm^{-3}]	840	764	769	773	760
Surface tension (20 °C) [mNm^{-1}]	26.7	23.0	23.2	23.5	22.6
Cetane ratio	48	71.5	64.6	57.7	78.4
Stoichiometric ratio	14.6	14.4	13.8	13.3	14.9

Test equipment and methods

The test engine is a 4100QBZL turbocharged Diesel engine, witch main parameters as shown in tab. 2. The engine is controlled by ET2000 measurement. The in-cylinder combustion pressure is obtained by Kistler 6125B and 4618A2 cylinder pressure sensors and charge amplifiers. The vibration signal of engine cylinder head is collected by 101156 sensor. The data acquisition equipment is a YE6232 B-type dynamic data collector. Data acquisition and calculation analysis are carried out by DEWE-800-CA-SE combustion analyzer of Devitron Company.

Under the condition of the static oil supply advance angle of the engine kept constant, the test of the speed characteristics under the 80% of throttle opening, and the load characteristics under the maximum torque speed (2400 Rpm), were carried out of 5 kinds of fuels, $0^{\#}$ diesel, FM5, FM10, FM15, and F-T.

Table 2. Specification of 4100QBZL Diesel engine

Type	4100QBZL
Cylinder diameter	100 mm
Piston stroke	105 mm
Engine type	Horizontal, four-stroke, water-cooled
Combustor type	Direct injection ω combustion chamber
Total displacement	3.298 L
Compression ratio	17.5
Rated power	70 kW
Rated engine speed	3200 Rpm
Rated torque [Nm rpm^{-1}]	240 Nm/2000~2200 rpm
Fuel supply advance angle	14±2 °CA

Experimental results and discussion

Analysis of the ignition delay period

When the high pressure fuel pressure reaches the starting pressure of the injector (24.5 MP), the corresponding crankshaft rotation angle is defined as the starting point of the injection. The starting point of combustion is the angle of crankshaft turning from negative value to 0 in the heat release rate curve. The ignition delay period expressed by crankshaft rotation angle. The ignition delay time has a significant effect on the fuel injection amount and premixed gas volume, and has a great influence on the combustion and vibration characteristics of the Diesel engine. Therefore, the ignition delay time is a key parameter. The ignition delay in a Diesel engine is the time lag from the start of injection combustion. This delay period includes physical delays in which atomization of the air fuel occurs, evaporation and mixing, and chemical delay due to the pre-combustion reaction.

Figure 1 shows the change in the retardation period of the five fuels at 2400 rpm with the crank angle (CA). It can be seen from fig. 1 that the ignition delay period of the five oils are shortened with the increase of the torque. Under the same torque, the retardation period of FT diesel is significantly shortened compared with 0$^{\#}$ diesel. Compared with FT diesel, the ignition delay of mixed fuel is prolonged with the increase of methanol content, and the increase is more obvious at low load.

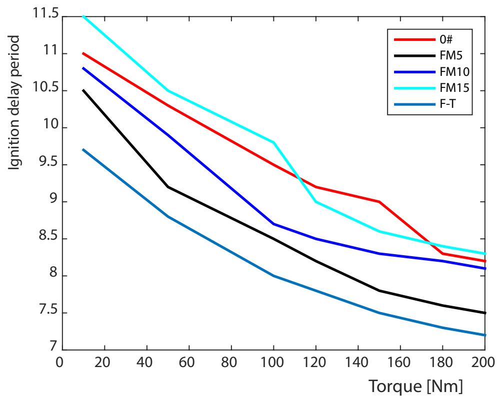

Figure 1. Effect of F-T/ methanol mixture fuel on ignition delay of Diesel engine

The fuel quality and the in-cylinder thermal state of the engine compression process determine the ignition delay period. The increase in load, the increase in temperature in the cylinder and the increase in pressure make the fuel easier to ignite and the ignition delay period is shortened. The F-T has shorter ignition delay period than 0$^{\#}$ diesel and other blended fuel due to has high cetane ratio, better evaporation and atomization effect, shorter physical preparation time, earlier ignition point and low temperature in the cylinder which is more affected by cetane ratio at low load. The cetane ratio of the fuel is reduced after methanol mixed with it, this leads to the deterioration of spontaneous combustion energy of the fuel. The heat absorbed in the evaporation process of mixed fuel is more, the temperature in cylinder is lower, the ignition lag period is obviously increased, so the ignition delay period of FM15 is longer than $0^{\#}$ diesel fuel.

Analysis of pressure rise rate

The in-cylinder combustion increase pressure rate can be used as a measure of combustion noise. The engine bench test study conducted in this research have revealed the relationship between combustion characteristics and noise. The higher the pressure rise rate, the higher equal capacity of combustion, the higher the cycle heat efficiency of Diesel engine. So high pressure rise rate is can improving power and economy of the engine, while which can increase combustion vibration. Thus moving parts are subjected to large impact loads, which shorten their life.

The pressure rise rate curve of five fuels when the engine working at different loads of 2400 rpm shown as fig. 2. The pressure rise rates of F-T, FM5, FM10, FM15, and $0^{\#}$ diesel are 0.63 MPa/°CA, 0.64 MPA/°CA, 0.74 MPA/°CA, 0.82 MPa/°CA, and 1.01 MPA/°CA. When fueling F-T, the peak pressure increase rate of the engine is obviously lower than fueling $0^{\#}$ diesel, and the peak phase is earlier. As the methanol content increases, the peak value of the pressure rise rate in the cylinder increases remarkably, and the phase lag of the peak is also observed.

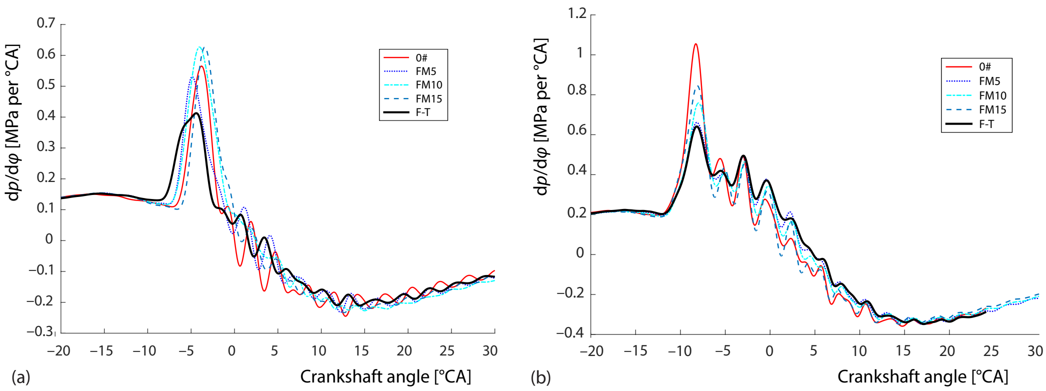

Figure 2. The effect of mixed fuel on increase rate of cylinder pressure of Diesel engine; (a) P_{me} = 0.038 MPa, (b) P_{me} = 0.76 MPa

The supercharging rate of the Diesel engine is mainly determined by the fuel ratio, and the physicochemical characteristics of the mixed fuel depend on the duration of the ignition delay period. As a kind of oxygenated fuel, methanol makes the speed of the combustion flame propagation fast and the change of cylinder pressure extremely fast. Therefore, as the methanol content increases, the increase in pressure rise rate is remarkable.

Analysis of instantaneous heat release rate

The optimization of the combustion characteristics of the internal combustion engine is mainly to optimize the heat release rate. The length of the heat release time reflects the cycle heat efficiency, and it has a great influence on the harmful emissions. So in order to make the Diesel engine run efficiently, the exothermic duration is generally between 40 °CA and 60 °CA, and it is hoped that the exothermic regularity will be satisfied quickly before slowly. The shape of the exothermic rate curve determines the ratio of heat release before and after, and has a great influence on the cycle heat efficiency and vibration and noise.

Figure 3 shows the heat release rate curves of five fuels at different loads of 2400 rpm. It can be seen from fig. 3 that as the load increases, the peak heat release rate rises. Compared with $0^{\#}$ diesel, the F-T diesel heat release is gentle, the peak value of the premixed combustion heat release decreases, the corresponding CA is advanced, and the peak value of the diffusion combustion heat release is increased. Compared with F-T diesel, the exothermic peak of the mixed fuel increases with the increase of the proportion of methanol, and the performance is more obvious at low load. At the same time, the exothermic rate during the diffusion combustion period is equivalent to F-T diesel at low load, and at high load.

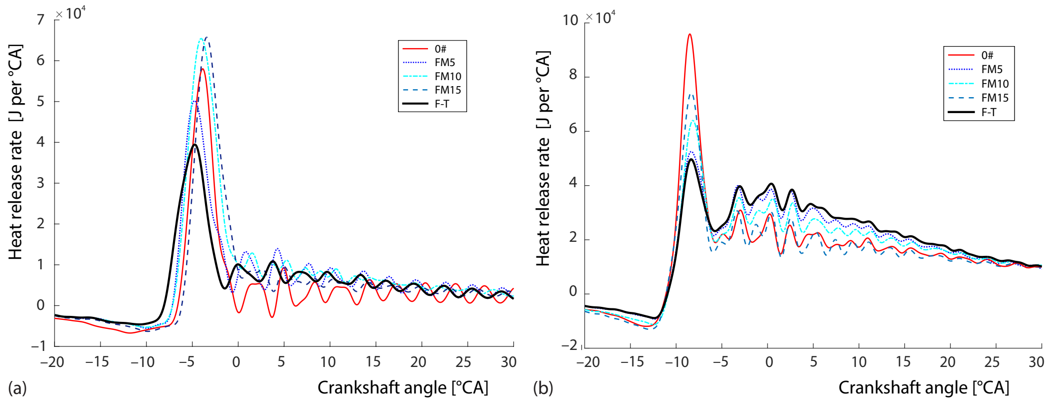

Figure 3. Instantaneous heat release of mixed fuel at 2400 Rpm; (a) P_{me} = 0.038 MPa, (b) P_{me} = 0.57 MPa

Fuel injection quantity and combustion heat release rate increase with increasing load. During premixed combustion period, with the increase of methanol content, the ignition delay period is prolonged, and the increase of combustible mixture content overcomes the influence caused by the decrease of fuel calorific value. So that the heat release rate of the combustion is obviously increased. In the diffusion combustion stage, the low distillation temperature of F-T, less heavy distillation components of the fuel are difficult to burn, the evaporation, diffusion and combustion rate of the fuel are accelerated, and the peak value of the exothermic rate is increased after the addition of methanol. Because of the low boiling point of methanol and the good atomization effect, the evaporation mixing rate of fuel is further increased, and the methanol oxygen content can promote the combustion and improve the combustion performance in the later stage, but the proportion of diffusion combustion decreases with the addition of methanol. The peak value of heat release rate in diffusion combustion stage has little or even slightly decreased.

Vibration of engine head analysis

The cylinder head of the engine is affected by various sources of excitation, including fuel injection, combustion and injector needle seat impact, as well as transient shocks. All of these are all these energies that are periodically on the engine casing based on the angle of rotation of the crankshaft [8, 9]. The four cylinders of the engine share a common head, and the head vibration acceleration sensor is installed in the middle position of the fourth head. Under the same working conditions, except for the oil difference, the influence of other factors on the vibration effect of the engine is the same. Figure 4 is a time domain signal of the head vibration acceleration in a working cycle of the engine, which was collected at n = 2400 rpm and P_{me} = 0.76 MPa, and the sampling frequency is 96 kHz.

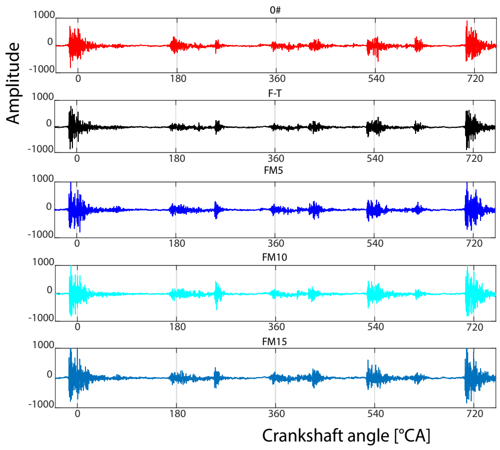

Figure 4. Time-domain waveform of vibration acceleration of head

According to the ignition sequence of the Diesel engine (4-2-1-3) and the phase diagram of valve distribution, it is easy to distinguish the response signals of excitation force as shown in fig. 4. The comparison of the time domain eigenvalues of the five types of oils under n = 2400 rpm and P_{me} = 0.76 MPa. The root mean square (RMS) refers to the effective value of the vibration signal, and it represents the magnitude of the vibration signal energy, which is generally regarded as one of the indexes to judge whether the mechanical device is running normally. If this value exceeds the normal value, this system may have a fault or trouble.

In general, the vibration level of the head increases with the increase of methanol content, which is consistent with the previous combustion situation. With the increase of combustible mixture amount during the delayed combustion period, the premixed combustion becomes more intense and the vibration increases. However, there is a situation that the RMS of F-T is larger than $0^\#$ diesel, which is not consistent with the previous combustion.

The main reason for this phenomenon is that the values of density and viscosity of F-T are small, and there are relatively large friction and pressure fluctuations during the fuel supply process. The impact increases when the delivery valve is closed, the injector needle valve is seated and the vibration increases. However, the vibration acceleration of the cylinder head is affected by the combustion excitation and the impact vibration of the injector needle. There are many factors affecting this shock vibration, such as the spring force of the maximum needle lift and the fuel pressure under the needle valve. The rate of reduction, the frictional resistance of the needle valve, the viscosity of the fuel, the spring stiffness, and the mass of the moving parts including the needle valve. The injector needle seat impact is ahead of the in-cylinder combustion excitation in phase. From the first two waveforms in fig. 4, it can be seen that the F-T diesel injector needle seating impact is greater than the $0^\#$ diesel vibration shock.

Table 3. Time domain characteristic parameters of each fuel vibration signal

The fuel	RMS [ms^{-2}]	Mean ampltude, P_k [ms^{-2}]	Crest factor	Kurtosis
$0^\#$	76.9349	882.94	11.4765	21.6807
F-T	78.9752	887.15	11.2333	29.3532
FM5	79.0601	1125.2	14.2322	21.3842
FM10	87.9829	1496.1	17.0044	31.8727
FM15	88.2593	1755.8	19.8937	42.5316

Kurtosis is used to describe the shock of the vibration signal, which is very sensitive to the shock characteristics. It is also the statistic of the distribution characteristics of the response vibration signal and is the normalized 4th order central moment [10]. In tab. 3, the kurtosis of each fuel is above 20, which is much larger than 3 (the kurtosis of the Gaussian distribution), which indicates that the probability density of the vibration signal deviating from the Gaussian distribution has obvious instantaneous impact on the engine [11-13]. The kurtosis value of F-T is higher than 0$^{\#}$ diesel, which indicates that F-T has the fast combustion speed, concentrated heat release and great impact on head. Adding a small amount of methanol can alleviate the shock vibration [14], but the large proportion of methanol mixed fuel makes it more sensitive to the impact of the engine, and the vibration impact is enhanced.

Conclusion

Based on this study and experimental results, the ignition delay period of F-T is much shorter than the other blended fuels and diesel. Because F-T has high cetane ratio, better evaporation and atomization effect, shorter physical preparation time, earlier ignition point and low temperature in the cylinder which is more affected by cetane ratio at low load. Experimental data shows that with the increase of methanol volume fraction then ignition delay period increases, the pressure rise rate increases, the combustion onset point is delayed, the combustion isobaric degree increases, the thermal efficiency increases and the vibration acceleration increases obviously the mixed fuel. With the increase of methanol content, the vibration of head intensified, the viscosity of mixed fuel decreases, and the wear of precise coupling parts of Diesel engine may increase. So the substitution rate of methanol is not too large. The combustion and vibration characteristics of each fuel should be considered synthetically to select the appropriate methanol blending amount.

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