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Influence of Different Fuels Physical Properties for Marine Diesel Engine

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Abstract

The physical properties and chemical mechanisms have direct relationship with combustion. The physical properties of different alternative fuels are researched on the effect of performance of marine diesel engine in this paper. The effect of in-cylinder pressure, emission products and the main species are compared. It can provides a direction for the researchers in established the CFD model. The results show that the in-cylinder pressure and temperature have large difference for different alternative fuels. The in-cylinder pressure and temperature are lower for the heavy oil. Due to the worse combustion, the soot mass has maximum value for heavy oil. The C14H30 and O2 mass have higher value at the start of combustion for the heavy oil. It also explains the combustion process of heavy oil.

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Keywords: Physical properities; chemical mechanism; different alternative fuels; marine diesel engine;

1. introduction

The environment pollute has been concerned all around the world. The marine diesel engine would cause worse environment pollutant compared with the vehicle [1]. The IMO (International Maritime Organization) has established more strengthen regulations, the Tier Ⅲ requires the quantity of NOx decrease to 3.4 g/Kwh [2]. It is necessary to reduce the quantity of NOx using all kinds of technologies, such as Exhaust Gas Recirculation (EGR),

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Selective Catalytic Reduction (SCR), waste heat recover and so on[34]. The simulation method has a great development with improving of computer level, which save more time, cost and resources.

The Computational Fluid Dynamics (CFD) coupled with the chemical reaction kinetics has been widely used in simulation of marine diesel engine. Liang et al.[5] research the EGR on the performance of marine diesel engine. The results show that with the increasing of EGR ratio, the cylinder pressure and combustion temperatures decreases and the peak of soot also shown a downward trend and more gentle, under the same load conditions. Pang et al. [6] investigate soot formation and oxidation process under two-stroke marine diesel engine using multi-dimensional CFD. The main result is that the averaged NO concentration is 7.7% lower as soot radiation is considered. Stratsianis et al.[7] research the effect of fuel post-injection on the performance of marine engine based on KIVA-3. Multiple fuel-injection strategies have proven to be effective in reducing pollutant emissions in heavy-duty diesel engines. The accuracy of CFD model has a direct effect on the result of simulation results. One CFD model includes many submodels, such as spay model, combustion model and toluene model. It is important to set every parameter.

As we all known, the set of fuel includes physical and chemical properties, especially for the marine diesel engine [8]. The marine engine fuel is complicated, the diesel used in the Emissions control area (ECA), and the heavy oil used in the others. The physical property of two fuels exists large difference. Pantazis et al.[9] developed and validated a CFD heavy fuel oil (HFO) model. The maximum cylinder pressure is significantly lower for the HFO compared with the Diesel. Kyriakides et al. [10]also made compared for two fuels. They can got same conclusion. The physical property of fuel has an effect on the performance of diesel engine. In this paper, the physical properties of different fuels are investigated. The effect of in-cylinder pressure, emission products and the main species are compared. It can provides a direction for the researchers in established the CFD model.

2. the CFD model

The CFD model is based on a marine diesel engine (6S35ME-B9). The structural parameters are listed in Table 1. The engine speed and power are 142 r/min and 3575 kW when operated at 100% load. The in-cylinder pressure and emission products were tested and used to validate the accuracy of the model. The CFD model was illustrated in other publish [11]. This paper also used the same model to research the physical properties of different fuels on the performance of marine engine. The CFD model integrated with the chemical reaction kinetics is used in this paper. The n-tetradecane used as the alternative fuel. The 62-species mechanism is used in combustion model.

Table 1. 6S35ME-B9 test engine specifications.

structure parameter	
Cylinder number	6
Bore (mm)	350
Stroke (mm)	1550
Displacement (L)	149
Connecting rod length (mm)	1550

The physical properties of C7H16, C14H30, Diesel and Heavy oil are compared on the effect of marine diesel engine performance in this paper. The physical properties of C7H16, C14H30 and Diesel are got from the CONVERGE company, which are existed in the data bank of CONVERGE 2.3 software[12]. The physical property of heavy oil can be found in the reference [10]. The liquid density of diesel and heavy oil is assumed to be constant, due to the complication of fuels. The density and critical temperature of evaporation are shown in Table 2. Fig.1 shows the comparisons of four alternative fuels in dynamic viscosity, surface tension, vapor pressure, and latent heat of evaporation.

It can be seen that the dynamic viscosity, surface tension, and latent heat of evaporation of heavy oil are higher than others with increasing of temperature. The dynamic viscosity is 1-2 orders of magnitude higher for heavy oil, the heat of evaporation is almost 2 times, and the surface tension is 30%-50% higher. However, the vapor pressure is lowest that others. These parameters are influence on the spray process of fuel, then, the combustion will be effect. It is necessary to choose the liquid property when the CFD model is established.

Table 2. The density and critical temperature of evaporation for four alternative fuels.

Alternative fuels	Density	Critical temperature
C7H16	Depend with temperature[12]	540
C14H30	Depend with temperature[12]	691
Diesel	1550	736
Heavy oil	149	928

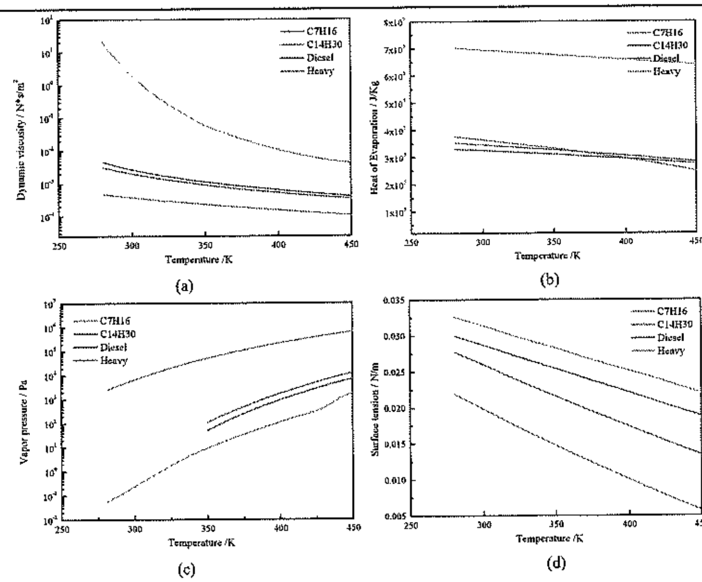


Fig. 1. the comparisons of physical properties for different fuels (a) dynamic viscosity; (b) heat of evaporation;. (c) vapor pressure; (d) surface tension

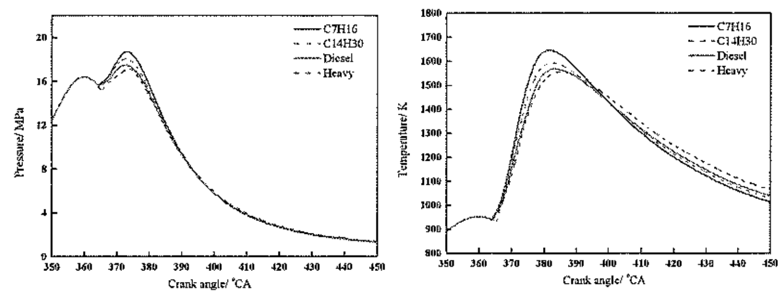
3. Results and Discussion

3.1. The effect of in-cylinder pressure and temperature

Fig.2 shows the in-cylinder pressure and temperature of marine diesel engine at four different liquid properties. From the Fig.2 (a), first, the maximum in-cylinder pressure is significantly lower for heavy oil. Second, the time of increasing combustion pressure is later. The increased surface tension will lead to lower Weber numbers, resulting in slightly slower atomization (Fig.1(d)). On the other hand, the lower vapor pressure makes evaporation rates lower (Fig.1(c)). The liquid property of heavy oil lend to the bad spray quantity. So, the combustion is worse when the heavy oil used in marine diesel engine. The results are agreement with the conclusions of reference [10].

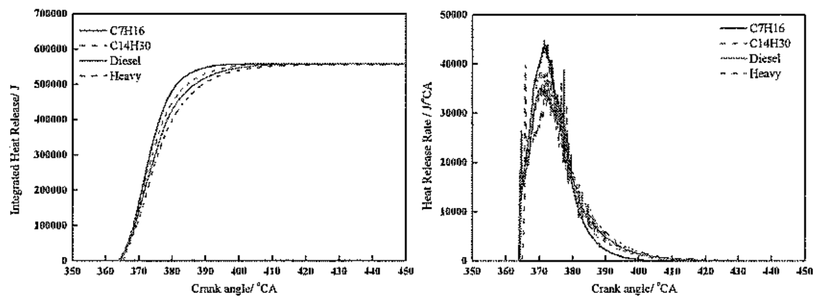
The in-cylinder temperature changes with crank angle under different liquid properties are displayed in Fig.2 (b) the maximum combustion temperature is lower for heavy oil. The in-cylinder temperature in the expansion stroke is substantially higher for heavy oil. The fuel combustion makes the temperature increasing quickly. The less fuel is burnt, due to the worse spray vaporization of heavy oil. However, more fuels will burnt during the expansion stroke. So, the temperature curve of heavy oil is smoothness compared with others fuels.

The integrated heat release and heat release rate also explain this phenomenon, which are shown in Fig.3. More fuels are burned in the expansion stroke for heavy oil. So, the heat release is higher for heavy oil in expansion stroke. The integrated heat release has little difference for all case. The lower heat release rate cause in-cylinder temperature decrease.



(a) Pressure (b) Temperature

Fig. 2. the comparisons of in-cylinder pressure and temperature for different fuels (a) in-cylinder pressure; (b) in-cylinder temperature



(a) Integrated Heat Release (b) Heat Release Rate

Fig. 3. the comparisons of integrated heat release and heat release rate for different fuels (a) integrated heat release; (b) heat release rate

3.2. The effect of emissions

As we all known, the regulations requires more rigorous for emission. The combustion has relationship with emission. The comparison of soot and NOx are shown in Fig.4. The NOx is generated under the condition of high temperature and enrich oxygen. From the Fig.4 (a), the NOx has a maximum value for C7H16. However, the quantity of NOx almost same for others cases. At the start of combustion, the oxygen is enrich for two-stroke marine diesel engine. The quantity of NOx is increase with the increasing of temperature. The maximum combustion temperature is higher for C7H16.

The quantity of soot has almost 5 times than that of diesel model for heavy oil in Fig.4 (b). The Hiroyasu soot model is used in this paper. The species C2H2 will be as predecessor of soot nucleate. Fig.5 shows the comparisons of C2H2 mass. It is obvious that the C2H2 mass is higher for heavy oil. The trend of C2H2 is agreement with that of soot. The worse combustion makes the uncompleted burned fuel increasing. The medium species increase, such as C2H2.

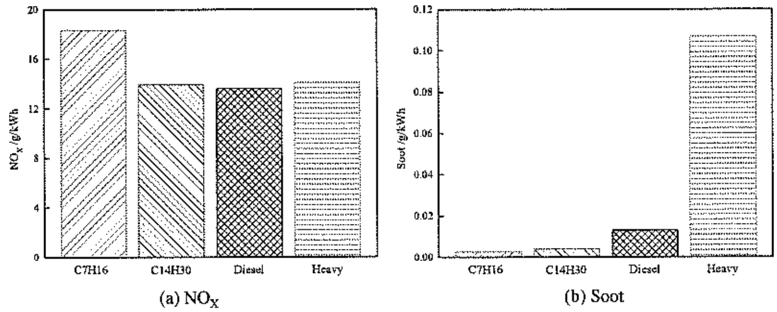


Fig. 4. the comparisons of NOx and soot for different fuels

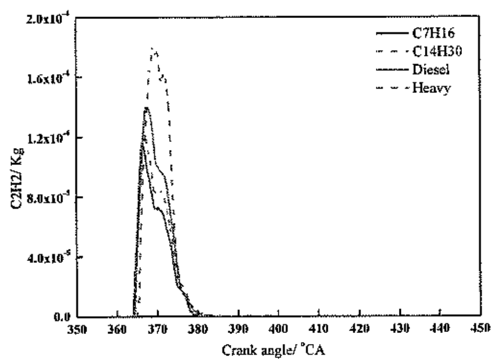


Fig. 5. the comparisons of C2H2 for different fuels

3.3. The effect of main species

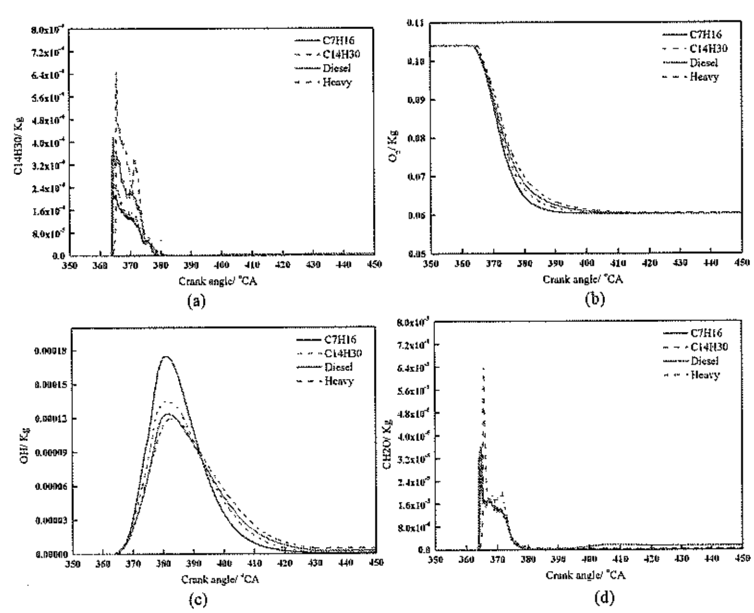


Fig. 6. the comparisons of main species for different fuels. (a) C14H30; (b) O2; (c) OH; (d) CH2O

The process of fuel combustion can be expressed by chemical reaction mechanism. The mass of main species are shown in Fig.6. From Fig.6 (a), the mass of alternative fuel C14H30 can be observed. At the start of combustion, the more C14H30 mass is unburned for heavy oil due to the worse spray atomization. With the combustion continue, the in-cylinder temperature increase. More heavy oil fuel are burned than others. The changes of O2 mass has also display this phenomenon.

The species OH is the main species of fuel first dissociation. The OH mass is opposite to the fuel mass. The OH mass is lower for heavy oil. It is also explained the fuel combustion for different alternative fuel. The CH2O mass displays the quantity of fuel changed to emission. From the changes of CH2O mass, it is seen that the emission is lower for heavy oil at the start of combustion.

4. Conclusion

The effect of physical properties are compared on the performance of marine diesel engine for alternative fuels. The main properties that affect spray atomization are the fuel viscosity and surface tension. The physical properties has been implemented in the CFD model of marine diesel engine. The results as follows:

The maximum in-cylinder pressure is lower for the heavy oil due to the worse spray atomization. At the same time, it also makes the in-cylinder temperature and integrated heat release lower.

The quantity of NOx has maximum value for the C7H16. However, the marine diesel engine produce more soot when the heavy oil are used.

The changes of C14H30 and O2 mass explain the worse combustion process of heavy oil. And the changes of OH and CH2O mass displays the emission changes with the combustion.

The different liquid property have large effect on the marine engine performance. The large different exist between the heavy oil and diesel, which make the performance of marine engine different. So, it is important to choose liquid fuels as alternative fuels of marine engine.

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Biography

Xingyu Liang received his Ph.D. degree from Tianjin University in 2006. He is currently an associate professor in School of Mechanical Engineering and State key Laboratory of Engines at Tianjin University, China. Fields of his research interests are combustion and exhaust control of diesel engine.