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A methane mode water–oil blended internal combustion engine (ICE)

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Abstract

In this paper, the authors analyze the combustion mechanism of the methane mode water–oil blended ICE in detail and the optimum water/oil ratio M_0, where $M_0 = -\frac{4n-m}{2}(\mathrm{mol_{H_2O}}/\mathrm{mol_{oil}}) = \frac{9(4n-m)}{12n+m+16y}(\mathrm{kg_{H_2O}}/\mathrm{kg_{oil}})$ (*n* refers to the number of carbon atoms of the oil molecule, *m* refers to the number of hydrogen atoms of the oil molecule, *y* refers to the number of oxygen atoms of the oil molecule,which is a methane module). The authors recommend two separate injection systems, one of which is the water injection system and the other is the oil injection system. As for the four stroke ICE, the water injection system begins to inject water at the moment when the air inlet valve is closed. As for the two stroke ICE, when the scavenge port closes after the air outlet valve, the water injection starts at the moment when the air inlet valve is closed. When the air outlet valve closes after the scavenge port closes, the water injection starts as soon as the scavenge port is closed. During water injection, its angular duration should be maintained within 30° CA, which will lead to higher combustion efficiency and relatively lower pressure of the water injection system, so that the reliability of the water injection system may be better guaranteed.

Keywords: Water–oil blended; Methane mode; Four stroke ICE; Two stroke ICE

1. Introduction

The idea of using water/oil mixture combustion to improve combustion efficiency was put forward as early as the 18th century. At the beginning of the 19th century, America, the USSR

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and other countries in Europe began emulsion oil research. Because of the lower technology and less pressing energy problem, the development of emulsion oil technology was rather slow. In the late 1950s, as the conflict between the environment and development became sharper and sharper and the petroleum crisis began to appear, the water/oil emulsion technology with its oil saving and emission reducing benefits became important once again. The oil–water emulsion was regarded as one of the three energy saving technologies at the First Annual Session of Internal Combustion Association in July 1981. Later, America, the USSR, Japan etc. took this technology as one of the national key projects to research and develop and made some beneficial achievements. With this technology, not only nitrogen oxides (NO_x) and particulate matter (PM) [1–22] but also carbon oxide (CO) and hydrocarbon (HC) emissions of ICEs are reduced. The ICEs combustion efficiency is improved too [12], while oil consumption is lessened [23,24]. The literature [25] reported a method called homogeneous charge compression ignition (HCCI) of controlling the ignition time through water injection. The literature [15] published a way to control detonation by injecting water into the engine's combustion chamber. The water–oil blended ICE has been made by Germany, France, Russia, Japan and America. There were more than 1000 automobiles running with emulsion oil in Aquazole Y, France, in January 2000, with 30% less NO_x and 90% less PM [12]. China conducted some researches in this field from the late 1950s and attained some achievements. At the beginning of the 1980s, because of less supply of energy, the Chinese National Planning Committee, Chinese National Science Committee and Chinese Science Academy jointly organized researches on oil–water emulsion fuel technology among the relative research institutes as well as individuals, and some practical achievements were obtained. Emulsion oil has been used on autobuses in some areas of China, such as Yantai, Dalian, Hangzhou and Shanghai cities.

Some technologies currently under research and development, including the complicated electronic control technology and the water–oil blended technology of the automobile engine, would affect the automobile industry deeply [26]. However, up to now, the proper water–oil blended combustion mode has not been found. Thus, the research on optimum water/oil ratio has developed little, which prohibits water–oil blended technology from being applied to the ICE universally. The literature [27–30] provides water/oil ratios ranging from 20% to 80% in volume. Ref. [31] publishes the water/oil ratio from 10% to 80% in volume, but the optimum ratio is not given. Ref. [32] provides that in combustion of the water–oil blended mixture, if the molecule of oil is regarded as C_nH_{2n+2}, the water proportion in the mixture should not be more than $18n/(32n+2) \times 100\%$. In this literature, the optimum water/oil ratio is not provided either. The literature [33] provided a set of on line water–oil emulsion systems, whose ratio of water to oil is 0.15–1 in volume. The literatures [7,15] publish that the water/oil mass ratio may be 0–1.5, when the water is injected into the ICEs combustion chamber. Nevertheless, all these literatures mentioned above do not publish the optimum water/oil ratio, so the authors provide a novel methane mode water–oil blended ICE according to the process of using energy from the higher carbon proportion to the lower carbon proportion, from the low proportion of methane and from methane to hydrogen. The water/oil ratio of the methane mode water–oil blended ICE is M_0. That is to say, the corresponding injected water in the ICE combustion chamber depends on the injected oil, and then, the combustion condition of the oil in the ICEs combustion chamber is similar to that of methane. Thus, the emission is lowered, while the power output is raised.

2. A ethane-mode water–oil blended ICE

The fuel of the methane mode water–oil blended ICE is defined as a kind of water/oil mixture, namely the water–oil blend, whose water/oil ratio is M_0, and $M_0 = \frac{4n-m}{2}(\text{mol}_{H_2O}/\text{mol}_{oil}) = \frac{(9(4n-m)}{12n+m+16y}(\text{kg}_{H_2O}/\text{kg}_{oil})$ and whose combustion condition is similar to that of methane or natural gas.

2.1. A fuel of methane mode water–oil blend

(1) When methane burns, the complete chemical reaction equation is as follows:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O \tag{1}$$

When oil with the mean molecular formula $C_nH_mO_y$ ($n \geqslant 2$, $m \geqslant 2$, $y \geqslant 0$) burns, the complete chemical reaction equation is as follows:

$$C_nH_mO_y + \frac{4n+m-2y}{4}O_2 \rightarrow nCO_2 + \frac{m}{2}H_2O \tag{2}$$

Adding M_0 mol H_2O to Eq. (2), provides

$$C_nH_mO_y + \frac{4n+m-2y}{4}O_2 + M_0H_2O \rightarrow nCO_2 + \frac{m}{2}H_2O + M_0H_2O \tag{3}$$

Multiplying Eq. (1) by the factor n provides

$$nCH_4 + 2nO_2 \rightarrow nCO_2 + 2nH_2O \tag{4}$$

Assuming the products of combustion of Eqs. (3) and (4) are equal, then the oil's methane module M_0 may be calculated as follows:

$$M_0 = \frac{4n-m}{2}(\text{mol}_{H_2O}/\text{mol}_{oil}) = \frac{9(4n-m)}{12n+m+16y}(\text{kg}_{H_2O}/\text{kg}_{oil}) \tag{5}$$

The oil's methane module M_0 means that when the water and oil mixture, namely the water–oil blend, burns, 1 mol of oil mixed with $\frac{4n-m}{2}$ mols of water, i.e. 1 kg of oil mixed with $\frac{9(4n-m)}{12n+m+16y}$ kg of water, the combustion products of this kind of water–oil blend is nearly the same as those of methane, so that an ideal methane mode combustion condition physically comes into being.

(2) As for the oxidation mechanism of methane, it is regarded that methane firstly loses the first hydrogen atom, then the second etc. until finally it turns into HCO. The hydrogen atoms taken away from the methane in the process of oxidation later create the intermediate products: H_2, HO_2, OH, H_2O etc., which then take part in the combustion reaction of methane, and especially the H_2O product takes part in the reforming reaction and HCO is produced, which is oxidized into CO and finally, CO is oxidized to CO_2 [34]. With regard to oxidation of hydrocarbons, it is regarded that the hydrocarbon firstly breaks off the carbon chain and loses hydrogen, then changes into a short chain hydrocarbon and continuously changes into a shorter chain one. The process above is repeated until a large number of HCHO molecules is produced, accompanied by a series of intermediate products such as CH_3, H, H_2, OH and H_2O. The produced CH_3, which is basically similar to the methane that has lost one hydrogen atom, is finally oxidized into HCO. The other intermediate products take part in the combustion reaction, especially the H_2O

products take part in the reforming reaction [35]. After that, HCO and HCHO are oxidized into CO, which is oxidized into CO_2 subsequently [36]. As far as the oil with oxygen is concerned, it firstly loses H_2O in the combustion and then repeats the process of the hydrocarbon's oxidation. As we can see from the statement above, when oil with the mean molecular formula $C_nH_mO_y$ ($n \geqslant 2$, $m \geqslant 2$, $y \geqslant 0$) burns, if water is put into the ICEs combustion chamber according to the oil's methane module M_0, the water and oil take part in the reforming reaction, and at the same time, the intermediate products take part in the combustion reaction. So, the water put into the ICEs combustion chamber participates in the whole combustion, especially at the last stage of combustion in which the combustion process of the oil is like that of methane, which demonstrates it provides an ideal methane mode water–oil blended chemical condition when the water/oil ratio is M_0.

(3) The main reason why the combustion emissions of NO_x of the water–oil blend are much less is that the deoxidization of the combustion field of this kind of oil is multiplied. When the water–oil blend burns in the ICE, the following reaction takes place:

$$H_2O + O \rightarrow 2OH \tag{6}$$

Then, the concentration of oxygen is reduced, which lowers the corresponding oxidation of the combustion place, i.e., the relative deoxidization is raised, and then, the formation of NO_x is greatly depressed.

Taking the fuel used for the Diesel engine as an example, the literatures [1,33] point out that when the water/oil ratio is 1:1, the combustion emission of NO_x may fall by about 85%. Ref. [37] demonstrates that when the Diesel engine uses natural gas, the emission of NO_x may be reduced by 40%. When the oil–water ratio is 1:1, the Diesel oil's combustion condition is close to that of methane. The reason why they have fewer emissions is that their deoxidization of the combustion place is stronger than that of the Diesel oil, largely leading to a depression of forming NO_x. The reason why, when the Diesel oil/water ratio is 1:1, the NO_x emissions are much fewer than that of natural gas is that the temperature of the former is lower than that of the latter, which offers a milder condition in temperature for forming NO_x, which is highly sensitive to high temperature. So, when the mixture of oil and water with the ratio M_0 burns, the deoxidization of the combustion field is similar to that of methane.

Blending different types of oil, $C_nH_mO_y$ $(n \geqslant 2, m \geqslant 2, y \geqslant 0)$, with water according to the ratio M_0, is physically, chemically and deoxidizingly forming a combustion condition like that of methane, which is referred to as the fuel of the methane mode water–oil blend.

2.2. A methane mode water–oil blend ICE

Methane mode water–oil blend ICE refers to an ICE *burning* the water–oil blend with the water/oil ratio of M_0.

2.2.1. A methane mode water–oil blend ICE with four stroke

A methane mode water–oil blend ICE with four stroke has two separate fuel supply systems, of which one supplies oil and the other water. Fig. 1 is the schematic of the port timing of a four stroke ICE with methane-mode combustion. In the water injection system, water injection starts

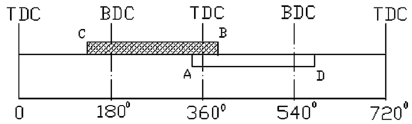

Fig. 1. Schematic of the port timing of the four stroke ICE with the methane mode combustion. Horizontal ordinate is the turning angle of the crankshaft; TDC: top dead center; BDC: bottom dead center; C: the open time of the air outlet valve; B: the close time of the air outlet valve; CB: the duration of the air outlet valve open; A: the open time of the air inlet valve; D: the close time of the air inlet valve; AD: the duration of the air inlet valve open.

at the moment when the inlet valve is completely closed, marked as D. During the whole process of water injection, the water injection angular duration is kept within 30° CA. Then, the injected water into the engine combustion chamber has no effect on the air change of the ICE, However, at the same time, the operational contents in the cylinder are increased, the pressure of the combustion chamber is increased too, the time for the injected water and air to mix is also relatively maximized, the combustion materials are enabled to blend more completely, so more stable and thorough combustion, more output power, much fewer emissions and relatively lower pressure of the whole water injection system can be obtained. Therefore, more reliability of the system can be guaranteed.

2.2.2. A methane mode water–oil blend ICE with two stroke

A methane mode water–oil blend ICE with two strokes has two separate fuel supply systems, one for oil and the other for water. Fig. 2 is one schematic of the port timing of a two stroke ICE with methane mode combustion, which demonstrates that the scavenge port closes after the air outlet valve. In the water injection system, water injection starts at the moment when the air outlet valve is completely closed, marked as F. During the whole process of water injection, the water injection angular duration is kept within 30° CA. Fig. 3 is another schematic of the port timing of a two stroke ICE with methane mode combustion, which demonstrates that the air outlet valve closes before the scavenge port. In the water injection system, water injection starts at the moment when the scavenge port is completely closed, marked as H′. During the whole process of water injection, the water-injection angle is kept within 30° CA. Then, the low pressure of the water injection system makes it possible to improve its efficiency, while not affecting the air change of the ICE when water is injected into the engine combustion chamber.

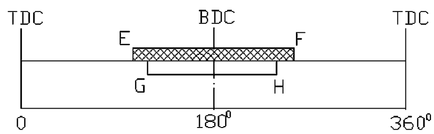

Fig. 2. Schematic of the port timing of the two stroke ICE with the methane mode combustion (1) Horizontal ordinate is the turning angle of the crankshaft; TDC: top dead center; BDC: bottom dead center; E: the open time of the air outlet valve; F: the close time of the air outlet valve; EF: the duration of the air outlet valve open; G: the open time of the scavenge port; H: the close time of the scavenge port; GH: the duration of the scavenge port open.

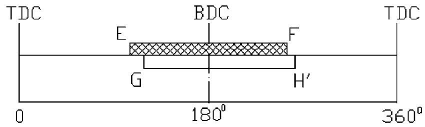

Fig. 3. Schematic of the port timing of the two stroke ICE with the methane mode combustion (2) Horizontal ordinate is the turning angle of the crankshaft; TDC: top dead center; BDC: bottom dead center; E: the open time of the air outlet valve; F: the close time of the air outlet valve; EF: the duration time of the air outlet valve open; G: the open time of the scavenge port; H′: the close time of the scavenge port; GH′: the duration of the scavenge port open.

3. Conclusions

As it can been seen from the combustion mechanism of the methane mode water–oil blend ICE, there are some beneficial consequences as follows:

- When the water/oil mixture (namely the water–oil blend), 1 mol of oil mixed with $\frac{4n-m}{2}$ mols of water, i.e. 1 kg od oil mixed with $\frac{9(4n-m)}{12n+m+16y}$ kg of water burns, its combustion products are like those of methane's combustion, thus forming an ideal condition known as methane mode combustion.
- As for the methane mode water–oil blend ICE with four strokes, it has two individual injection systems, one for Diesel and the other for water. Water injection starts at the moment when the air inlet valve is closed, and the water injection angular duration is 30° CA. As for the methane mode water–oil blend ICE with two strokes, when the scavenge port closes after the air outlet valve, the water injection starts when the air inlet valve is closed, and the water injection angular duration is 30° CA. When the air outlet valve closes after the scavenge port, water is injected at the moment when the scavenge port is closed, and the water injection angular duration is 30° CA. Then, the water injected into the engine combustion chamber does not affect the air change of the ICE, and as a result, the operational materials in the cylinder are increased, which leads to an increase of the output power. Meanwhile, the relatively lower pressure of the water injection system is obtained, which makes it possible to get more reliability of the water injection system.
- Compared with the existing water–oil blended ICE, the methane mode water–oil blended ICE takes advantage of the water/oil ratio M_0, which integrates the strengths of both liquid fuel and gas fuel, such as natural gas. The methane mode water–oil blend ICE is based on the fully scientifically ideal mode of water–oil blend combustion. Accordingly, with its great significance to environmental protection and energy saving, it reduces the reluctance of people to explore the field of water–oil blend combustion.

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