The study of fuel mixtures with palm oil

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Abstract. The search for alternative fuels for heat engines is an urgent task for scientists around the world. For diesel engines, vegetable oils seem to be the most promising. The use of a partial addition of vegetable oils to diesel fuel allows us to reduce the consumption of hydrocarbons and not cause significant changes in the design of the engine, as well as affect the composition of the exhaust gases. For countries producing palm oil, including Nigeria, this method is economically viable. This article presents the results of computational studies of the features of the combustion process of biodiesel fuel with additives of palm oil and hydrogen peroxide and the effect of additives on the ignition delay period and the combustion process. The calculations have shown the effectiveness of using hydrogen peroxide as an additive to the biofuel under consideration to reduce the ignition delay period and, consequently, improve the power and economic indicators.

Keywords: diesel, alternative fuels, biofuel, biodiesel, palm oil, ignition delay period, hydrogen peroxide additives.

1. Introduction

Transport plays a huge role (over 55% [1]) in forming demand on oil and liquid biofuels worldwide. The stock of hydrocarbons reduces, that is why in some countries the research of alternative fuels for internal combustion engines are held. According to the forecast of energy development worldwide [1] demand on liquid fuels increase in Africa is expected – on 73%: from 183 mtoe in 2015 to 316 mtoe in 2040. Alternative fuels are expected to become 20% of overall energy demand [1] by 2040.

Ethanol and biodiesel – are two most common biofuels [2]. Biodiesel fuel could be produced from a wide specter of vegetable oils. Interesting reviews of biodiesel fuels production give useful information about typical content of original source of fat acid [3-9].

Vegetable oils are a perspective source of alternative fuels. There are more than 350 cultures, such as sunflower, soy, seeds of cotton, rapeseed and peanuts which are potential alternative fuels for diesel engine. [10] the actual usage of vegetable oils in diesel engines meets certain difficulties due to the difference of physical and chemical properties between vegetable fats and petroleum fuels. Disadvantages of those fuels in comparison with diesel fuels are higher viscosity (2-10 times), bad dispersion and auto oxidation [11], bad low-temperature characteristics, low cetane number, high ignition temperature, increased coking ability. In addition to this, calorific value is 7-10% lower than diesel fuels because of the oxygen compounds. That is why vegetable oils are usually used as fuels after refining or in a mix with diesel or alcohol fuels.

Lately, developing countries, such as Malaysia, Indonesia, Thailand, Nigeria pay great attention to the production of biofuels from internal, renewable resources.

Nigeria is in the TOP-10 of palm oil producing countries. Car transport in Nigeria implements the main amount of cargo and passenger transportation [12]. Agriculture occupies 65% of the population. According to The Global Petroleum Club, palm oil has the highest productivity (among plants) in kilograms and liters of oil received from hectare.

Application of the palm oil as a supplement to the main fuel in transport sector in agriculture of Nigeria, allows reaching significant economy of fuel, reduce transport costs of petroleum and decrease
the amount of flue gases, raising environmental friendliness of diesel transport used in agricultural areas of the country.

Indonesia and Malaysia are world leaders in palm oil production. Scientific research is held in those countries in order to use palm oil as the alternative fuel for diesel engines.

Having physico-chemical properties of vegetable oils compared [13], it is possible to say that palm oil in a number of characteristics (heat of combustion, stoichiometric ratio, cetane number etc.) is the closest to the traditional diesel fuel. At the same time palm oil has some serious differences in characteristics from traditional petroleum fuel (kinematic viscosity, freezing temperature) and that makes it impossible to use pure palm oil in diesel engines without changing the construction of the engine and fuel system. Therefore, mostly acceptable way is using diesel fuel with supplement of palm oil in diesel engines without significant construction changes.

Power and economical rates of engine’s work mainly are defined by burning process, therefore, features of biofuel burning process need to be examined basing on palm oil and determine the influence of the hydrogen peroxide and ethanol supplements under consideration on the process. On the basis of this research develop method of biodiesel fuel burning control based on palm oil.

2. Materials and methods
There are two processes depending on fuel’s reactivity abilities, which need to be pointed out: mixture of air and fuel auto-ignition moment and process of laminar flame diffusion.

Next processes take place while fuel burns inside diesel engine:
1. Fuel injection and spraying
2. Evaporation of the first portions of fuel with generation of homogeneous mixture of air and fuel
3. Auto-ignition of the evaporated fuel in generated mixture of air and fuel
4. Evaporation of the fuel left and its combustion in diffusion-limited mode (turbulent diffusion of fresh air outside torch’s line)

During the research of reactivity ability of diesel fuel with supplements based on palm oil (further it will be called biodiesel) and its mixtures with peroxides comparative calculations both auto-ignition characteristics (ignition delay) and laminar flame characteristics (laminar flame speed) are of interest.

Auto-ignition and diffusion of the laminar flame are determined by the speeds of chemical reactions. Appropriate chemical model of burning should be chosen for fuel combustion.

Chemical model of biodiesel fuel burning (list of the substances with their thermodynamic and thermophysical properties, list of reactions with approximations correlations between speed constants and pressure/temperature) is suggested in the work [14] for a wide range of fuel components, including biodiesel fuel based on palm oil. Verification of this mechanism took place basing on a great amount of experimental data of auto-ignition delay and laminar flame diffusion speed in air and fuel mixtures. Therefore, this model is used in this research to evaluate burning characteristics of the biodiesel fuel and biodiesel fuel with supplements in comparison with diesel fuel.

The analysis of the accepted model [14] shows that it includes such components as hydrogen peroxide H₂O₂ and ethanol C₂H₅OH, also intermediate products and their dissociation reactions, interactions with oxygen from the air, radicals. Therefore, this model can be applied for analysis of the influence of hydrogen peroxide and ethanol on auto-ignition and laminar burning of biodiesel fuel based on palm oil.

Diesel fuel has complicated composition, for calculations n-heptane based model fuel is used and it is chosen so its cetane number would match diesel’s. Its burning model was verified on a number of experiments and it is also taken from [14], which is versatile for a whole group of hydrocarbon fuels.

Next issues are to be solved in order to evaluate burning properties of biodiesel fuel and influence of hydrogen peroxide and ethanol supplements on the burning process:
1. Match characteristics of biodiesel fuel based on palm oil and model diesel fuel based on n-heptane, including ignition delay and laminar flame speed for distinctive diesel engine working modes basing on the kinetic calculations.
2. Study increasing of reactional ability of biodiesel fuel based on palm oil in relation with volume fraction of hydrogen peroxide and ethanol supplements (gas phase) in comparison with original biodiesel and diesel fuels.

3. Results and discussion.
A series of calculations and studies of model diesel fuel, pure diesel fuel base on palm oil and with supplements of hydrogen peroxide (mole ratio from 0 to 0.1 relating to biodiesel fuel) and ethanol (mole ratio from 0 to 0.1 relating to biodiesel fuel) auto-ignition characteristics took place in order to solve existing problems.

Results of the ignition delay calculations of the model biodiesel fuel based on palm oil without supplements and biodiesel with hydrogen peroxide supplements are shown in figure 1.

![Figure 1](image)

Figure 1. Ignition delay of stoichiometric mixture of biodiesel fuel (based on palm oil) and air (pure and with hydrogen peroxide supplements), diesel fuel and air, biodiesel fuel with supplements of hydrogen peroxide: initial pressure 40 bars, initial temperature 800-1400 K.

Results of the ignition delay calculations of the model biodiesel fuel based on palm oil without supplements and biodiesel with ethanol supplements are shown in figure 2. All calculations were made under next conditions [15]:
- Pressure in the system 40 bars;
- Initial temperature from 800 K up to 1400 K;
- Stoichiometric air-fuel mixture;
- Hydrogen peroxide and ethanol supplements from 1 to 0.1 moles on 1 mole of fuel.

Diesel and biodiesel fuel based on palm oil ignite almost at the same time at high temperatures, over 1000 K. Main differences could be noticed at initial temperatures lower than 1000 K, which are mostly common for the diesel engine auto-ignition conditions. Biodiesel fuel ignites significantly later (differences in auto-ignition delay may reach 100% with initial temperature 800 K). Hydrogen peroxide supplements in 0.02 to 0.1 moles range on 1 mole of fuel can significantly change reactional ability of biodiesel fuel based on palm oil. With initial temperatures at 1000 K - 1100 K and hydrogen peroxide supplements from 0.02 moles/(moles of fuel) ignition delay reduces on 0.2 ms and becomes lower than diesel fuel. In the range of temperatures from 800 K – 1000 K hydrogen peroxide supplements from 0.1 moles/(moles of fuel) allow to reduce the ignition delay on 0.15 ms, which brings biodiesel based on palm oil noticeably closer to the ignition delay parameters of diesel fuel.
Figure 2. Ignition delay of stoichiometric mixture of biodiesel fuel (based on palm oil) and air (pure and with ethanol supplements), diesel fuel and air, biodiesel fuel with supplements of hydrogen peroxide: initial pressure 40 bars, initial temperature 800-1400 K.

Ethanol supplements to biodiesel based on palm oil do not give us considerable increase of the reactional ability of the fuel being studied (Figure 2).

A series of calculations took place next to research characteristics of laminar burning of homogeneous mixtures of biodiesel fuel based on palm oil and air with hydrogen peroxide (mole ratio from 0 to 0.1 relating to biodiesel fuel) and ethanol (mole ratio from 0 to 0.1 relating to biodiesel fuel) supplements. Reliance of calculated speed of laminar burning with hydrogen peroxide and ethanol supplements concentration is presented in figure 3. Values of laminar flame in biodiesel mixture fuel/air and diesel fuel (n-heptane)/air are taken as reference levels. All calculations were made under next conditions [15]:
- Stoichiometric mixture fuel-air;
- Fresh mixture temperature 300 K;
- Pressure 1 bar;
- Hydrogen peroxide and ethanol supplements 0-0.1 mole/(moles of fuel).

Figure 3. Diffusion speed of laminar flame in stoichiometric mixture of biodiesel fuel (based on palm oil) and air (pure and with ethanol supplements), diesel fuel and air. Pressure 1 bar, initial temperature 300 K.
Hydrogen peroxide and ethanol supplements to biodiesel fuel based on palm oil do not change significantly laminar flame speed in stoichiometric fuel-air mixture (Figure 3) and laminar burning process cannot be substantially accelerated with considered supplements.

4. Conclusions
Even 0.02 moles of hydrogen peroxide supplements on 1 mole of fuel (or 0.0025 g of peroxide on 11 grams of fuel, approximately it is 2 ml of peroxide on 1 liter of fuel) provided the reduction of ignition delay to the numbers comparably lower than diesel. The highest effect hydrogen peroxide in such small concentration may cause on fuel ignition at temperatures 1000 K – 1100 K and make initially less reactional biodiesel fuel more reactional than diesel fuel. Inside low temperature area the efficiency of the supplements to the fuel reduces and concentration of hydrogen peroxide may be increased.

Presented results of the calculations, dependence of the ignition delay from the initial temperature and concentration of the supplement (hydrogen peroxide) permit to suggest the next method of biodiesel fuel based on palm oil burning process control. Having set initial temperature of auto-ignition, it is possible to determine the exact amount of hydrogen peroxide needed to provide auto-ignition delay equal or close to biodiesel fuel with the same conditions. Fuel injection system should supply calculated values of hydrogen peroxide relating to engine working mode in future.

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