



Obstacles in the Utilization of Biodiesel as the Fuel in Small Stationary Combustion Units

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The presented paper deals with the obstacles in the utilization of biodiesel in small stationary combustion units. The aim of the paper is to discuss the technical problems related to the combustion of biodiesel by means of two different types of atomizers, namely the pneumatic effervescent atomizer and the pressure spill-return swirl atomizer. The technical problems are described based on the comparative combustion tests that were carried out at the nominal heat duty about 1000 kW. The tests were carried out at the experimental burner testing facility, whose main apparatus is the water-cooled combustion chamber.

The first part of the paper describes the influence of the physical-chemical properties of the methylester of rape seed oil (RME) on the quality of combustion. The properties of RME are compared to the physical-chemical properties of the most commonly used standardized liquid fuel in small stationary combustion units, namely extra light heating oil (ELHO). There were identified two properties of the RME, namely the flash point and the shape of distillation curve, which cause the problems with the combustion stability by the application of both mechanisms of the atomization.

The results of the combustion tests showed that it is required to preheat the RME at the temperature higher than 60 °C and it is useful to use a small gas stabilization burner to stabilize the spray ignition in close proximity of the atomizer head. The next increase of the preheating temperature above 80 °C leads to the significant increase in nitrogen oxides formation, however simultaneously, the stability of the flame becomes better and the carbon monoxide formation decreases.

The negligible difference between ELHO and RME was observed in the heat transfer rate to the water-cooled chamber shell. On the other hand, the problems related to the RME spray drops evaporation causes that the maximum heat transfer shifts in the direction further from the burner mouth.

The second part of the paper is aimed at the assessment of the possibility of the substitution of the ELHO by RME or some of the vegetable oils from the general view. It may be concluded that the requirements on the RME combustion are evidently harder than for ELHO. It mainly concerns the quality of atomization and the quality of mixing of fuel drops with the oxidizer.

Generally speaking it would be better to focus the research on the development of the pressure atomizer and on the decrease of the burner nominal heat duty to the range between 200 and 500 kW. This fact is related to the possibility to utilize these fuels at the decentralized units and/or as the stabilization fuel during the combustion of renewable solid fuels or waste. It is not recommended to use renewable liquid fuels as the main fuel at the large stationary combustion units since it could cause their shortage in other areas of economy.

1. Introduction

The quality of combustion of any fuel depends on meeting the conditions under which is the particular substance combustible without extensive burdening of the environment. From the renewable fuels point of view should this assumption be even more important. We can also assume that a fuel can be used only if there is a financially and operationally acceptable technical solution. This is a problem that is currently in case of combusting liquid fuels from renewable sources (i.e. various products of esterification or oils themselves) on stationary combustion units not entirely solved in technical aspects. Currently there are various types of experiments focused on combustion of clean methyl esters or their mixtures with ELHO on oil boilers with the output up to 50 kW primarily designated for family houses heating. The results in the area were published for example by Daho et al. (2009) and Ng et al. (2010). The authors publish in accordance with each other an increase of production of nitrogen oxides, a lowered production of CO and problems with combustion and ignition of the mixture when the mixture contains a share of biodiesel higher than 30 %. Alonso et al. (2011) presents an overview of technologic possibilities when combusting biodiesel in small stationary units used for heating households. However, his results are in contrary with the statements of the previous authors about problems with combusting biodiesel.

There is significantly lower number of experiments with burners with output of hundreds kW. Souza et al. (2008) published the results of the test of block burner with the output of ca. 200 kW on the water-cooled combustion chamber. The published results show that there are changes in the visible size of the flame and in lower heat transfer in the water-cooled shell of the combustion chamber in comparison with the results when combusting ELHO. Carraretto (2004) carried out long-term comparative tests of combustion of biodiesel and ELHO at the output of 200 – 500 kW at different surpluses of combustion air

Although the results are similar to the previous author, the need of changing some components that are degraded chemically by the biodiesel is here stated explicitly. Ghorbani et al. (2011) used a block burner with the output of 150 kW that uses pressure atomization for his experiment. He confirms the results of some authors that during combustion of biodiesels the production of CO decreases significantly and the production of NO_x increases.

In general we can state that the tests of the burners with the output of hundreds of kW are carried out according to the possibilities of the particular workplaces. The key problem of these tests is mainly the construction of the testing combustion equipment that often does not answer to real conditions under which are the liquid fuels combusted. That is the reason for the effort to approximate the two below described experiments to the real conditions that are in stationary heating equipment as much as possible.

2. Discussion of the properties of ELHO and RME

Particular values of different biodiesels' characteristics were published by different authors, are comparable and do not show considerable deviations. When we consider differences of physical-chemical characteristics between ELHO, RME, we can find out, on the basis of tests that had been carried out, that the key characteristics that influence burning are the flash point temperature and the shape of the distillation curve. In case of rape oil to these two characteristics belongs also much higher viscosity.

Lowering the viscosity of the rape oil to a level where it can be dispersed well. The viscosity of RME is comparable to the viscosity of ELHO. The results of atmospheric distillation of ELHO and RME are shown in Tables 1 and 2. The values of temperature of the flash point of ELHO and RME reach a difference approximately 90 – 100 °C, where the ELHO standards usually state the minimal temperature of the flash point higher than 56 °C. In case of RME the temperature of the flash point differs between 130 and 150 °C.

The importance of the difference of the influence of the distillation curves on the combustion process can be seen mainly in their influence on the time needed for complete combustion of the fuel, where

the fuel first has to be evaporated during the flight of a droplet through the flame and only after that it starts to burn. This problem can be solved by preheating RME on a higher temperature. The preheating influences the quality of combustion in several ways: it lowers the viscosity (the size of the droplets decreases during atomization, which causes a better ratio of the surface and volume of the droplet), it lowers the difference in temperatures of the liquid and the flash point and last but not least it shortens the time needed for heating of the droplet. Thus it can be said that also only a moderate preheating on 50 – 60 °C can improve significantly the combustion process of RME.

This is similar also in case of rape oil, but the main reason of the preheating is mainly enabling of acceptable atomization. The viscosity of the rape oil is at a temperature of surroundings considerably higher than in case of RME, which is one of the reasons of its esterification.

3. The Testing Equipment and the Used Burner and the Conditions Common to Both Experiments

Tests of combustion of ELHO and RME with two different types of atomizers, effervescent and split-return atomizer, at different temperatures of preheating were carried out. The atomizers were installed on a combined burner. The ignition and stabilization of combustion were carried out by a pilot burner with the output of 20 kW. The orifice of the burner has the diameter of 300 mm and at the level of the outlet of the atomizer a swirler was installed.

The tests were carried out on a water-cooled experimental combustion chamber that enables tests of burners with the output up to ca. 1800 kW (inner diameter 1000 mm and length 4000 mm). The chamber is divided to seven separate water-cooled sections, which enables measuring of absorption of heat along the length of the flame. The whole testing equipment is able to collect and record automatically all the data needed for setting and evaluation of the experiment.

Before the beginning of the data collection was the combustion chamber always set to a stabilized state where the maximal difference of the average output temperature of the flue-gas must not be in 30 minutes higher than 10 °C.

4. The Test with Effervescent Atomizer

For the test of the pneumatic atomization a effervescent nozzle with six outlets with the diameter of 1.0 mm, diameter of mixing chamber of 10 mm and with 40 locking holes with a diameter of 0.8 mm was used. Its design was carried out according to Jedelský (2009). As an atomizing agent pressure air was used. The nozzle was tested in three different gas to liquid ratios (GLR), namely 10, 15 and 20 % of the weight. The pressure air used for atomization has the temperature of the surroundings.

The RME was dosed at three different temperatures of preheating, namely 30, 70 and 110 °C. The atomization air was not preheated. The test was carried out at three outputs, namely 475, 700 and 900 kW at a constant surplus of the combustion air defined as 6 % of volume of O₂ in dry flue-gas. The pressures needed for dosing the amount of liquid did not exceed 10 bar. An observation of the stability of the flame at a turned-off stabilizing burner and measurement of the heat absorbed in particular section of the shell of the combustion chamber were part of the experiments.

To sum up the results of this test, these basic characteristics of the results can be stated:

1. During the combustion the preheating of the RME has a significant impact. At the temperature around 30 °C problems with stability of the flame were apparent and storing of the fuel inside of the combustion chamber occurred. This phenomenon occurred mainly at the lowest output (475 kW) at 10% GLR. The increase of the temperature of the dosed RME caused a significant stabilization of combustion and lowering of storing. At higher outputs only increase of stability of the flame, also in comparison with ELHO, was observed. The reason for more stable combustion is mainly better atomization that is caused by lower viscosity and higher pressure of the liquid and gas in front of the burner (thermal expansion of the liquid) and also reduction of the difference between the temperature of the flare (or the beginning of the distillation) and the temperature of the dosed liquid.

2. With increasing temperature of preheating of RME are the emissions of CO lowered and the concentration of NO increases significantly. The concentrations of CO are considerably lower than at the ELHO combustion. On the other hand when preheating on 110 °C, the production was significantly higher than in case of ELHO combustion. The decrease in CO production is caused by the improvement of the combustion process, which also leads to higher temperatures in the core of the flame and with that also to higher production of thermal nitrogen oxides. The nitrogen oxides production is also caused by the direct presence of chemically bounded oxygen in the RME molecules.
3. The visible size of the flame of RME shortens depending on its preheating, the flame is sharper and it is possible to observe a higher intensity of its radiance. The area of the maximal intensity of transfer of the heat into a water-cooled shell of the combustion chamber shifted by ca. 0.5 m away from the burner. The amount of the heat absorbed into water is approximately on the same level; with increasing temperature of the preheating of the RME causes a moderate increase of the amount of the absorbed heat.

5. The Pressure Atomizer Test

The second used atomizer was a split return type pressure atomizer. The atomizer was chosen mainly because of its simple construction and the ability to atomize and regulate very well in comparison to pressure nozzles without backward flow, Lefebvre (1989). Geometric ratios of the atomizer were chosen so that the fuel flow on the atomizer entry was max. 600 l/h. Regulation of the output was carried out by regulation of the pressure on the return pipe of the fuel. The pressure before the entry of the fuel into the atomizer was kept constant. The diameter of the nozzle was X mm, diameter of the whirling chamber was X mm. Four input vents with the diameter of X mm enter the whirling chamber. The maximal pressure of the dosed fuel (ELHO and RME preheated on 50, 80 and 110 °C) was ca. 1.9 MPa.

The basic goal of this test was to verify the behaviour of the RME when the pressure atomization of fuel is used. This enables its usage in case of small burners, in which pneumatic atomization is hardly defendable because of high investment and operational costs. The test was carried out at outputs of 600, 800, 1000 and 1200 kW and the excess of the combustion air of 4, 6, 8 and 10 vol. % of oxygen in dry flue gas. During the experiment the stability of the flame with stabilizing burner turned off was observed and measuring of the heat absorbed in particular sections of the combustion chamber shell.

From the measured data similar behaviour as in case of effervescent nozzle as described above can be assumed. The key outcome of this test is reaching stabilized combustion with regulation extent of the nozzle up to 1:2 without sedimentation of the fuel in the combustion chamber area. In more detail, the results can be described as follows:

1. The results confirmed the behaviour of the preheated RME, namely from the emission production and stability of the flame points of view. With increasing temperature of the preheating the CO concentration decreases and the NO concentration increases significantly.
2. The concentration of CO is very dependent on the output and the excess of combustion air. If the optimization of the burner's geometry is done and good mixing of the fuel and the combustion air is ensured, it will be possible to achieve a problem-free combustion of RME preheated on a temperature around 50 °C at the excess of combustion air of 4 vol. % of the oxygen in dry flue-gas. This should lower the production of thermal nitrogen oxides – although the temperature of the flame will rise, the significance of lowering of partial oxygen pressure will predominate.
3. The preheating of the RME on 50 °C can be considered low enough to be carried out also in case of smaller combustion units without the need of installing temperature-resistant but costly parts used for combustion of heavy fuel oils.
4. The absorption of the heat into the combustion chamber shell showed similar values as in case of the effervescent atomizer. The shift of the position of the maximal heat flow to a greater distance from the burner was in case of RME observed again.

6. Conclusion

The issue of combusting the products of esterification on stationary combustion units can be viewed from different perspectives, namely environmental, political, economic etc. It is necessary to technically solve the dosing of esterification products into the combustion area so that they can be considered as applicable as a substitute of fossil fuels.

The size of the equipment on which the technical optimization should be carried out should be mainly stationary units with small outputs (ca. 100 – 400 kW) that can be applied as small local sources of thermal energy, e.g. for heating. At higher outputs the effort should be to directly combust vegetable or animal fats.

The main reason is the lowering of production demands and preventing the production of glycerol phase that is a by-product of esterification. Although is the glycerol phase that consists mainly of glycerine, alcohol, water and dissolved hydroxide further used as a source of clean glycerine, its acquisition is highly energy-demanding. The energy intensity of the production then negatively influences the overall CO₂ balance that can be even negative.

The experiments showed that the products of esterification are usable in case of stationary combustion units. However, due to their accessibility it will be necessary to focus the research on units with significantly smaller outputs than the ones in these experiments. Research in the area of atomization and mixing fuel with oxidizer so that it was possible to minimize temperature of preheating of the biodiesel and simultaneously ensure quality combustion with minimum emission of CO and NO_x should be crucial. Simultaneously, ignition by an electric discharge should be solved. In connection with the production of emissions has to be said that these are qualitative result. For the outputs about 1000 kW a smaller combustion chamber has to be used, if we want to simulate accurately the flue pipe of the boiler with a nominal output of 1000 kW.

Although are currently carried out experiments also on very small stationary thermal sources used in family houses, where mixtures of methyl esters and classic fuel oil are used, the authors believe that this way of production of mixtures is only a temporary solution. Mixing is another operation that increases costs and the final price of the fuel. The price competitiveness of biodiesels in comparison with ELHO is then dependent on the policy of the given country, i.e. on the degree of taxing of particular fuels and the support of renewable fuels.

Overall, it is necessary to realize that the raw materials sources for biodiesel production (i.e. above all crop acreages) are in direct competition with crop acreages for vegetable oils production for food industry and it is not possible to extend them endlessly. The import of liquid fuels from renewable sources outside of the country of consumption means creating further energetic dependency.

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