

Experimental study on combustion of liquid renewable fuels

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The present paper is focused on experimental study of combustion of liquid fuels. Liquid fuels can be categorized as standardized fuels made of oil and as non-standardized fuels coming from renewable sources or as residues from oil or coal processing. At present period mainly liquid fuels from renewable sources are more often discussed as the source of thermal energy, which can be utilized in other processes. In this paper the study is focused on one standardized fuel, namely extra light heating oil (ELHO), and two non-standardized fuels, namely rapeseed oil and distilling residue of fatty acid methyl ester of rapeseed oil (DRME).

The main aim of the performed research is to provide experimentally the performance of different liquid fuels at heat duty about 1 MW. The study is carried out at an advanced burner-testing facility for testing gas and liquid fuel burners. There is no need for preheating of extra light fuel oil since its viscosity is sufficiently low. On the other hand the studied non-standardized fuels need preheating up to 70 °C prior to entering the burner. The investigation focuses on the influence of kind of fuel and burner operating parameters on the flame stability, the flame shape and the complete combustion.

1. Introduction

Incineration of liquid fuels has been for a long time among methods of heat energy generation which may be further utilized depending on the installed technology. This long term experience has lead to normalization of individual types of liquid fuels. Alternative liquid fuels in the form of waste and/or liquid fuels from renewable sources tend to prevail lately due to rising prices of heat oils caused by ever rising consumption (with financial market swings) and due to thin oil supplies. In addition to raw oil price, political decisions on taxes, greenhouse gases emission limits and energy dependence along with diplomatic relations with particular countries play vital role too.

Industrial utilization of liquid fuels from renewable sources for combustion in stationary equipment is researched only sporadically. Main purpose is to minimize payment for CO₂ emissions. This mostly concerns pilot projects of combined combustion of solid fuels from renewable sources with an option of additional combustion of liquid fuels

from renewable sources for units with heat power of dozens and hundreds of MW. Additional combustion of liquid fuels from renewable sources is usually installed for the purposes of heat power stabilization.

Despite limited numbers of published papers, we may assume that utilization of liquid fuels from renewable sources for heat power reaching from hundreds of kW to MW is subject to research and development by industrial businesses. Concerning very small heat power, tests were carried out for boilers with heat power of 50 kW designed to heat small scale premises, e.g. experiments by Daho et al. (2009) who combusted mixtures of ELHO and cottonseed oil in an unadjusted unit with heat power of 18 to 40kW and San Jose Alonso et al. (2006) who conducted similar experiments with various mixtures of ELHO and rapeseed oils in a boiler with heat power of 26 kW. Both state problems with ignition of the fuel with high portion of vegetable oil using electrical discharge. Authors, however, do not give a detailed description of the burner installed in the boiler. We may assume it is a pressure atomization. The same relates to experiments on combustion of transesterification products by Tashtoush et al. (2003) who give up to 5.5 kg/h as amount combusted which corresponds to heat power of ca. 55 kW. This experiment used laboratory water cooled furnace and was carried out by pressure atomization using spill-return atomizer type. Experiment results of combustion on power burners and block burners with heat power of hundreds of kW used for boilers and steam generators of small heat power are hard to access.

Considering the above mentioned, the objective of research was set to assess qualitative and quantitative differences in combustion of ELHO, rapeseed oil and DRME. Emission along with observation of behavior of flame visible part were among main parameters of research analysis together with tests focused on comparison of amount of absorbed heat in cooling water under stabilized conditions. Tests were carried out with pneumatic effervescent atomizer with maximum heat power of oil at ca. 120 kg/h with pressure of 1.0 MPa depending on physical chemical properties of combusted fuel. Pressure air served as atomization medium. Tests were conducted in water cooled horizontal combustion chamber with maximum heat power of 1,400 to 1,800 kW depending on geometric configuration of the burner and fuel type.

2. Media

2.1 Tested fuels

Potential alternative liquid fuels coming from sources available in Central Europe, i.e. rapeseed oil, DRME (with distillation temperature reaching 344°C) were selected for qualitative and quantitative comparison of combustion. ELHO was opted as a reference fuel easily available on the market. This fuel is used for unit of small heat power reaching dozens of kW up to unit of MW in areas where there is no natural gas available due to its high heating value, low content of chemically bound sulphur and nitrogen and simple storing. Authors are aware that LHO might serve as a more suitable reference fuel which also needs preheating temperature of 40 to 50°C. Contractors, however, supply it only in large amounts.

Comparison of important physical chemical properties influencing combustion of particular liquids in stationary equipment is given in Table 1. Viscosity and density

were measured at authors' facilities. Gross heating value, high heating value and content of carbon, hydrogen and sulphur were determined in a certified laboratory.

Table 1: Basic physical chemical properties of researched fuels

		ELHO	Rapeseed oil	Distillation residue - FAME
High heating value	MJ/kg	45.1	40.5	40.8
Lower heating value	MJ/kg	42.6	37.9	38.0
20°C viscosity	cSt	4.7	67.8	64.9
60°C viscosity	cSt	-	13.5	11.2
Preheating temperature (10 cSt)	°C	-	ca. 70	ca. 70
20°C density	kg/m ³	836	912	880
60°C density	kg/m ³	-	871	864
Ignition point PM	°C	>56	135	170
Carbon content	%wt	86.8	78.3	78.5
Hydrogen content	%wt	12.6	11.9	12.9
Oxygen content	%wt	0.5	9.8	8.5
Sulphur content	%wt	< 0.1	<0.1	<0.1
Calculated stoichiometric air	m _N ³ /kg	11.19	9.91	10.23

2.2 Atomization medium and combustion air

Pressure air was opted as an atomization medium for all experiments with all 3 types of fuels. Amount of air was determined in dependence to fuel rate and required gas to liquid ratio (GLR). Temperature of atomized air was selected with respect to design of fuel and air supply pipes in the burner. Pressure air was not preheated for ELHO. Pressure air was preheated at the temperature of 90 °C for rapeseed oil and DRME which was measured at a preheater outlet so that subcooling of oil at the inlet is avoided. Atmospheric air of the ambient temperature was used during experiments.

3. Burner used

3.1 Basic configuration of the burner

Tests were carried out at experimental power burner with two-stage gas supply with an option of oil atomizer installation. Atomizer is mounted to the central burner pipe. Diameter of the burner body where the combustion air flows and inner diameter of burner stone is 300 mm. Primary gas head is a part of a central pipe with an eight blade swirl generator attached to it. Outer diameter of the swirl generator is 240 mm, pitch angle of the blades is 35°. Burner is equipped with gas ignition burner of 18 kW.

3.2 Atomizer used

Quality of liquid fuels combustion is significantly influenced by the atomizer used. Atomizer has to secure atomization of the fuel into sufficient drop size. Drops then evaporated during their fly through the flame and gases are burned. Liquid fuels of oil origin which are mixtures of compounds with carbohydrate chains of various lengths tend to evaporate depending on their boiling point, which makes their combustion easier. Liquid fuels from renewable sources are mixtures of compounds as well,

however, with longer chains of carbohydrates. This has a negative impact on boiling point and consequently on the speed of drop evaporation. Thus we may assume that it is necessary to secure improved atomization than for atomization of liquid fuels of oil origin.

Based on preliminary experiments, effervescent atomizer with maximum heat power of 120 kg/h and fuel pressure of 1.0 MPa, 15 % GLR was opted. Atomizer was equipped with a jet with 6 nozzles of 1 mm diameter and span angle of 30°. Atomizer was mounted to supply pipe of oil and atomization medium which consists of weldment of coaxially situated pipes.

4. Testing facility

Tests were conducted in a burner testing facility equipped with a horizontal combustion chamber of 1 m diameter and 4 m length which is cooled by water. Water cooling of the inner shell is divided into seven sections with independent measuring of flow rate and cooling water temperature. Maximum heat power of the burner depends on flame shape and combusted fuel and may reach 1,400 to 1,800 kW. Combustion chamber is equipped with 8 inspection holes along its length. Two inspection holes are situated in front opposite the burner. Flue gas is released from combustion chamber through flue gas ducting of 0.5 m inner diameter. Pressure in the combustion chamber is measured in a front part of the burner in accordance with standards for burner testing. Flue gas temperature is measured in a flue gas ducting beyond the combustion chamber as well as sampling for continuous flue gas analysis. TESTO 350XL flue gas analyzer with incorporated flue gas cooler was used for the testing. The analyzer was equipped with O₂, CO, NO, NO₂, SO₂ electrochemical sensors.

Dosing device for liquid fuels is equipped with two dosing circles, i.e. dosing circle for light heat oils (LHO circle), and dosing circle for heavy heat oils (HHO circle) with an option of preheating of fuel up to 130 °C. First type of circle was involved in ELHO testing; the other type for rapeseed oil and DRME testing. Flow rate, temperature and fuel pressure are measured prior to entering the burner.

Combustion air inlet is equipped with devices for measuring of flow rate, temperature and pressure. Preheater of pressure air is installed, if needed, between inlet and burner connection with devices for measuring of temperature of outlet air.

Testing facility allows for automatic data collection with time periods of 1 second, 2 minutes and on a command of operator.

5. Description of the test

Objective of the testing lied in a comparison of combustion of ELHO and rapeseed oil and DRME. Visual properties of the flame, deposition of the fuels in the combustion chamber, combustion stability with no support by stabilization burner and emission concentration were observed effects during the tests.

Experiments were carried out for all three types of fuels with heat power of 0.9 MW, 0.67 MW and 0.475 MW and combustion air surplus 6 % O₂ in dry flue gas. GLR was opted at three levels, i.e. 10, 15 and 20 %. Although effervescent atomizers allow for lower GLR than 2% (Jedelsky et al., 2009), minimum 10 % GLR was opted due to anticipated problems with combustion of liquids from renewable sources. Prior to onset

of testing, combustion chamber and flue gas ducting were in the state of stabilized thermodynamics of 1 MW heat power, air surplus of 3 % O₂ in dry flue gas and running on natural gas. Onset of data collection was conditioned by stabilized temperature of flue gas in flue gas ducting which could never exceed 10 °C over the period of 30 min. Data collection followed for the period of 5 min and they were assessed later. Particular types of fuel were tested separately. Quality test and combustion stability test were followed by visual check up of the atomizer whether the jets are fouled or not. Atomizer was cleaned then, if necessary.

6. Summary of results

Following results were acquired by the evaluation of experimental data:

1. Compared to combustion of ELHO, visible instabilities of flame were observed during the combustion of liquids from renewable sources with no support by stabilization burner. Both rapeseed oil and DRME were preheated up the temperature, at which their viscosities are comparable to viscosity of ELHO, i.e. cinematic viscosity was lower than 10 cSt. It may be supposed that the atomization of sufficient quality was ensured in all cases. The densities of all fuels can be considered approximately consistent at dosing temperature. The distinction between the densities of ELHO (820 kg/m³) and DRME (855 kg/m³) makes only 35 kg/m³ (the measurements of surface tensions of ELHO and FAME from rapeseed oil carried out by Ejim at al. (2007) show the similar difference, namely approximately 10 %). This difference can be considered negligible at the pneumatic atomization. It can be supposed that observed combustion instabilities are caused by the different chemical composition of ELHO and fuels from renewable sources. It follows that physical-chemical properties of investigated fuels are different, as well. It concerns mainly temperature of boiling point of each chemical component of fuel that influences the evaporation of drops, and temperature of ignition point.
2. It was observed that fuel starts to deposit in the combustion chamber at low heat power 450 kW and GLR 15 % during combustion of liquids from renewable sources. This state occurs in case of combustion ELHO at only GLR 10%, although overpressure of fuel and pressure air prior to burner is double during combustion of DRME at GLR 15 % (ca. 0.36 MPa) in comparison to combustion of ELHO at GLR 10 % (ca. 0.17 MPa). Thus better atomization was expected. The deposition of the fuel in the combustion chamber does not occur for higher heat powers, since the quality of atomization increases with increasing pressures. Therefore in order to achieve of safe atomization and burnout of liquids from renewable sources it is necessary to use higher GLR than at ELHO.
3. The tests that were focused on the evaluation of amount of heat absorbed in cooling water revealed, that less heat is absorbed in the shell of combustion chamber during the combustion of fuels from renewable sources. Flue gas temperature of ELHO is lower approximately for 30 to 40 °C depending on burner heat power in comparison to flue gas temperature at the outlet of combustion chamber during the combustion of liquids from renewable sources.

4. Formation of NO increases with increasing heat power and GLR during the combustion of rapeseed oil. When DRME is combusted at GLR 10 %, the increase of CO is evident. The CO increase is caused by problematic atomization at GLR 10 % that is described above.
5. Insignificant differences in consumption of combustion air per unit of heat power were observed during the experiment. This fact tends to be positive, since then high temperature differences will not occur in the area of furnace that are caused by low consumption of combustion air per unit of fuel. Low air consumption may be caused by the presence of chemically bounded oxygen in fuel.
6. As to the size of visible flame, no substantial differences were observed for each fuel. This fact represents one of the prerequisites that the combustion chamber has not to be extended for the use of fuels from renewable sources. However, the modifications of combustion chamber's geometry can not be excluded, since a flame tube used for water heaters and steam generators, which are equipped with block burners, is directly blazed with flame. Nevertheless it should be prevented from the touch of fuel drops with cool surface.

7. Conclusion

The text gives only a short description of experiment and results for the reason of limited extent of the article. The experiment was focused on the comparison of combustion properties of one standardized liquid fuel, namely ELHO, and two liquid fuels from renewable sources that are available in Central Europe, namely rapeseed oil and distilling residue of fatty acid methyl ester of rapeseed oil. In general it was proved that more emphasis must be placed on the quality of atomization and the burner construction if the fuels from renewable sources are used. Next the fuels must be preheated to higher temperatures in comparison to oil fuels with similar viscosity in order to shorten the time needed for heating and evaporation of drops during their fly through the flame. However, this brings higher demands for burner construction.

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