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BUDAP E S T UNI V ERS I T Y OF TECHNOLOGY AND ECONOMICS

FACULTY OF MECHANICAL ENGINEERING

SUMMARY OF PhD DISSERTATION

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M.Sc. in Mechanical Engineering

UTILISATION OF LIQUID BIO-FUELS IN HEAT ENGINES

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I. Antecedents of research

The world's electricity demand, and hence greenhouse gas emissions are growing. The growth rate could be reduced by using renewable energy sources.

Biomass is one of the most important renewable energy in Hungary. The two most important liquid fuels which can be obtained from biomass are alcohol and vegetable oil and its esterified version. Using esterified vegetable oils has been already established practice in several countries. It is, however, costly to produce. Because of these considerations I deal with cold-pressed rape seed oil in my work.

Besides tractor fueling one possible area of application of rape seed oil besides tractor fueling in agriculture is on-site application or distributed power generation.

One possible implementation is the permanently installed microturbine with generator or diesel engine. There are to ways when using new fuels: either we alter fuel so that it would be applicable in older devices or we make the device capable of using new fuels.

The NO_x emissions decrease of modern gas turbines is achieved through substantially increased excess air ratio. The method has its limitations, however, because flame burns with large air ratio are prone to burning instability, which could be thermoacoustic oscillation (formation of acoustically self generating flames), unstable ignition or local flame burn-out as well. Thermoacoustic oscillation testing is the central task of the current gas turbine research.

Crude rape seed oil viscosity and evaporation characteristics differ greatly from that of the diesel oil. Using rape seed oil causes deposition in the combustion chamber of the engine, hence is fuel adjustment needed. The revised fuel is rape seed methyl ester (RME). The RME production, however, is expensive and byproducts are sources of some additional problems.

II. Critical review of the literature

Acoustically self-excited flames

Based on literature data it is clear that rape seed oil can be used in gas turbines (eg [Ardy, 1995], [Just, 2000], [Gökalp, 2004]). Unfortunately, the authors did not examine what atomisation quality the rape seed oil combustion with gas turbine atomizer needs and how it could be achieved.

According to Just’s experience acoustic impulsive self flames develop more often when using biofuels, but he did not examined the evolving picture of spray in detail [Just, 2000].

Herman sent the fuel into the model combustion chamber with swirl pressure atomiser [Herman, 1995]. During measurements with Laser Doppler Anemometer (LDA) he measured the flow of liquid and air. He noted that in the case of oscillation the fuel gets into the chamber unevenly, so the release of heat also becomes uneven, and the place of flame front changes periodically as well. According to his suggestion, to avoid the oscillation, one possible solution could be the application of other fuels with different kinetic properties.

Müller examined the evaporation occurring on the edge of the airblust atomiser. He simulated the emerging oscillation with sinusoidal excitation of the primary and secondary air [Müller, 2005].

With the bisection of viscosity the average Sauter diameter changed by only approximately 6%, however, it increased by 51% with the triplication of the surface tension.

When bisecting then quartering the pulsation amplitude the droplet diameter did not change. Based on his work we expected to get larger droplets in the case of rape seed oil.

Internal combustion engines

Vegetable oil in internal combustion engines was used by many and in many different ways. (Crude, esterified, with alcohol, mixed with gasoline, in engine chamber with direct injection, with constant/variable load and speed etc). The operation of the engine and the results of measurement are affected by the vegetable oil's quality as well (year of manufacture, etc.).

The properties of rape seed oil were tried to get converged to diesel in different ways. Zoldy examined the cetane number and viscosity of the triple mixture of bio-diesel, diesel and ethanol in his work [Zoldy, 2007].

On the basis of Plassmann's measurements, methanol interblends with gasoline and water well, but poorly with diesel and even worse with vegetable oil [Plassman, 1974].

Karabektas blended isobutanol with diesel oil (in 5, 10, 15 and 20 vol%), it examined the impact on performance and emissions in single-cylinder direct-injection diesel engines. He experienced the reduction of NO_x and CO emissions and the increase of CH emission [Karabektas, 2009].

According to his final conclusion, isobutanol mixes with diesel well and without disjunction, and carrying out conversions on the engines is not necessary either. In his work he could not reach so far to execute his experiments with the mixture of alcohol and rape seed oil.

Spessert and his co-workers examined single-cylinder diesel engines in rape, sunflower, and RME-operation. During that investigation they measured the rate of performance, torque, emissions, the pressure evolving in the injection system, smell and noise-emission [Spessert, 2007].

Kumar and his colleagues measured the emissions in single-cylinder engine, at constant speed using vegetable oil (castor bean), a mixture of vegetable oil + methanol, diesel, and vegetable oil–esther. During their measurements they found that alcohol decreased smoking. The NO_x emissions were lower with vegetable oil than with diesel. (This is due to lower combustion temperature.) The combustion of the mixture of vegetable oil and its esthers showed a longer diffuse phase than diesel. According to their measurements, ignition delay is higher with using vegetable oil than with diesel. Peak pressure and pressure increase was the lowest in the case of measuring vegetable oil [Kumar, 2003].

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III. Aims of the research

An adaquate quality vaporisation of liquid fuels is essential for both the use of a gas turbine and a diesel engine. Since the density and surface tension differ from that of the conventional gas turbine fuels (ie. kerosine) and diesel oils, it is necessary to investigate the vaporability of renewable fuels distinctly.

In my thesis, based on the above, I aimed to examine the form of spray and the thermoacoustic oscillation occurring in lean combustion, when using rape seed oil in different atomisers, as well as the application in internal combustion engines.

During my work I compare the thermoacoustic oscillations which evolve in lean combustion in the combustion chamber of a model gas turbine equipped with airblust atomiser , in the case of using conventional (kerosine jet-A) and renewable (rape seed oil) gas turbine fuel. I focus my attention especially on the phase-separated examination of the oscillations which occur in the course of using different fuels. I intend to investigate the speed, direction and diameter of the droplets.

I look into the possibilities of increasing the combustion velocity of vegetable oil during the examination of the application of vegetable oil in engines. Therefore I blend various types of higher alcohols to it.

Besides the applicability of the resulting motor fuels I will also inspect their other properties such as the flash point, viscosity, density, cold filter plugging point, which are important from the aspect of storage and transportation.

In my work (which contains 64 figures, a bibliography with 129 items on all together 93 pages and 5 chapters and 11 pages of appendix) I present the research job I have done for the sake of achieving my objectives, the experimental devices used and the theoretical implications of the question.

IV. Research methods

To examine the self-excited flames I built a pilot gas turbine combustion chamber (fig 1.) By virtue of its construction, the device excludes the formation of non-self-excited flames. The architecture of the chamber allowed touch less and point-like (PDA) examination of the spray on extended surfaces (laser light sheet, PIV). The measuring devices gave an opportunity for a phase separated analysis of the oscillating flame (droplet size, droplet velocity).

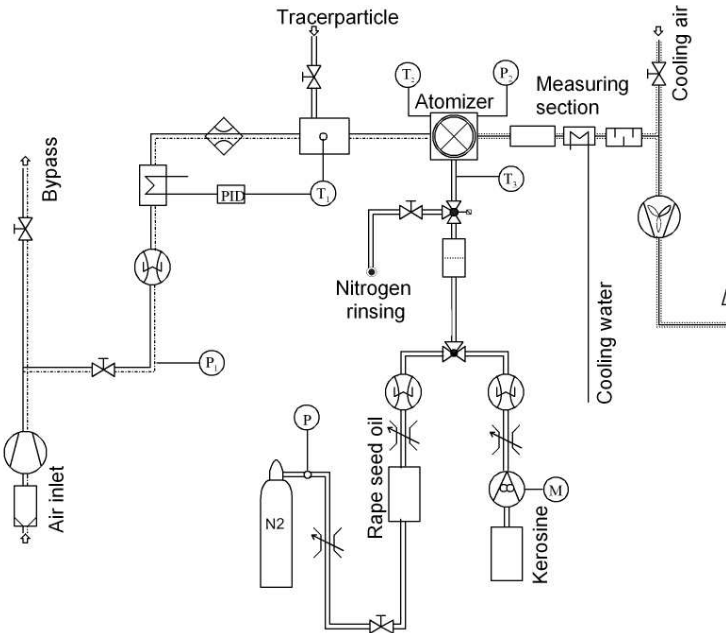

Fig. 1. Test rig to the research ont he self excited flames

The analysis of pure rape seed oil and the blend of higher alcohols and rape seed oil in internal combustion engine were done with a CFR cetane rating unit.

I used laser shadowgraphy (fig. 2.) besides the widespread TGA for analysing the properties of evaporation.

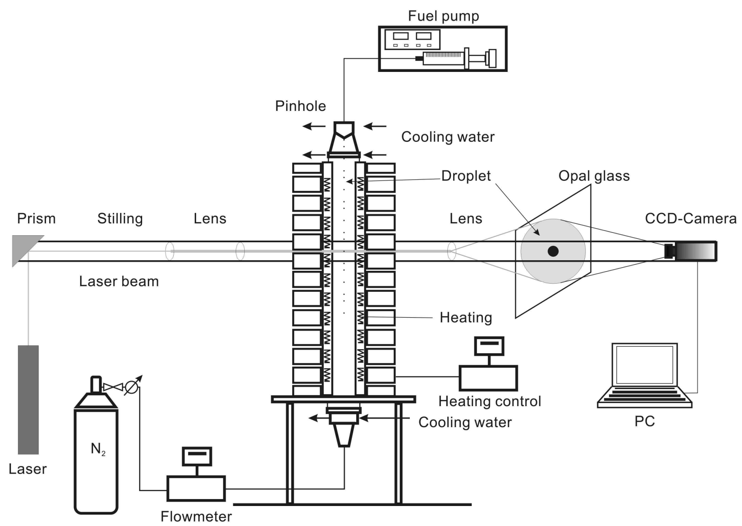

Fig. 3. Shadowgraphy

I executed the examination of the other physical properties (flash point, combustion heat, viscosity, density, cold filter plugging point, oxidation stability etc.) of the blends according to the relating standards' prescriptions.

V. New scientific achievments

1. In the case of high-viscosity fuels, using swirl pressure atomiser, the same droplet size of atomisation can be achieved as with using duplex burner. Therefore using a pressure atomiser is energetically more expedient. In the case swirl pressure atomiser, increasing temperature to 60 °C at 10 bar improves the vaporability of the liquid just as much as increasing the temperature of the 60% higher pressure by only 30%. I proved all these results with experiments [1], [2].

2. In the case of self-excited flames, when using an airblust atomiser, in the instance of both the not easily volatile higher viscosity rape seed oil and kerosine, oscillation phase angle does not affect the axial direction of droplets, but it does affect their axial and tangential velocity. The affect of the oscillation on axial velocity is 36% in the case of rape seed oil having 100% higher surface tension and 130% higher viscosity (comparing to the maximum value), and it is -50% in the case of kerosine. The affect of oscillation on tangential velocity is -20% and -33% by turns [3], [4], [5], [6], [7].

3. I used experiments to prove that in the instance of oscillation combustion rape seed oil and kerosine results similar processes of CO és NO_x formation as a function of both excess air and heat performance brought in [3], [4], [5], [6], [7].

4. I proved that higher alcohols examined together with rape seed oil interblend up to 20 volume percent without volume contraction. As known, simple alcohols will not interblend with rape seed oil, but when mixing them with water considerable volume contraction emerges. (When using ethanol-water mixture of 50 volume percent it can reach 3.7%, but usually remains around 1-2%) [9].

5. In a single cylinder antechamber diesel engine it is expedient to mix propanol or butanol to rape seed oil up to 20 volume percent for the sake of decreasing viscosity and improving combustion process. Among the tested alcohols butanol is better than propanol from the point of view of using it in engines because of its higher heating value. Affects of alcohols on cetane number and viscosity of blends are the same. Even 20 volume percent buthanol decreases cold filter plugging point to the level prescribed for summer season. Blended alcohols have no impact on oxidation stability. Buthanol decreases (counting with the same volume) the flash point of the blend more, hence it has a higher fire and explosion hazard [8], [10], [11], [12].

6. I proved the presumption, whereas the combustion of an alcohol-rape seed oil mixture proceeds in the engine’s combustion chamber in two steps: the rape seed oil with higher cetane number burst into flames first. Then its flames ignite the high antiknock quality alcohol evaporating from the blend. With applying experiments I proved that the evaporation of alcohol from rape seed oil-alcohol droplets begins even at low temperatures (under 30 °C), the proportional rate of evaporation grows as temperature rises. Above 180 °C droplets do not contain any alcohol, only rape seed oil, which at this temperature will not evaporate [10], [12], [13].

7. With execution of some measurements I proved that the emission of a mixture of rape seed oil and higher alcohols used in an antechamber diesel engine is affected by alcohols in the same order, independent from their types. I pointed out that in the case of blending alcohol to rape seed oil in 10 and 20 volume percent levels, the change in the emission is not linear with the progression of alcohol content. I presented the function of the change with the diagram of the measuring points [14], [15].

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