

OPTICAL RESEARCH ON THE FUEL INJECTION INTO A DIESEL ENGINE FOR DIESEL FUEL, RME AND RAPE OIL

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Abstract

The paper presents the results of the research on the influence of diesel fuel, rape oil methyl esters and rape oil on the evolution of the jet, velocity of the jet front and the atomization/spraying apex angle versus the crank angle of the engine. Measuring was performed using a single-cylinder Diesel engine with direct fuel injection and the apparatus AVL Engine VideoScope. It was found that physical and chemical parameters diversifying the tested fuels significantly influence the parameters of the sprayed fuel jet. It applied mainly to the increase of the fuel atomization apex angle for the fuels of high viscosity as compared with diesel fuel and to different course of the range and velocity of the jet front versus the engine crank angle. Large and heavy drops of vegetable oil have initially higher velocity than for diesel fuel. However, very soon, the velocity of rape oil jet front decreases to a lower value than for the petroleum fuel.

From the visualisation process we can observed real start of injection and combustion processes. From these measure - delay of self-combustion in diesel engine. Delay of self-combustion for natural rapeseed oil is shorter than for standard diesel fuel. As a result of this fact, we can observe in next research lower combustion dynamic, lower max. combustion temperature and lower concentration of NOx in exhaust gases.

A change of the organization of the injection process of tested fuels can bring on differences in the combustion course.

Keywords: alternative fuels, Rapeseed oil, RME, injection, visualization

1. Introduction

The optimizations of energy parameters as well as the reduction of toxic exhaust components in diesel engines fuelled by alternative fuels require a more precise organization of the injection and combustion process [2]. In order to optimize the processes occurring inside the cylinder of an engine fuelled for example by bio fuels, the analysis of the variation of principal energy parameters of an engine is not sufficient any more. For a direct estimation of the fuel injection course and of the way to create a fuel-air mixture, its self-ignition and combustion, the possibility of a visual examination of these phenomena becomes necessary [1]. There are many essential problems concerning the recording of images inside the cylinder of a combustion engine. The most important are: high temperature and working medium pressure, influencing the optical element of the measuring apparatus, deficiency of sufficient place in the modern engines heads for optical access to the cylinder interior and a very high speed of registered phenomena variation.

These problems were solved practically by, for instance, an Austrian firm AVL, which produced VideoScope 513D system, allowing registering and analysis of the fuel injection and combustion in a diesel engine cylinder. This paper presents the results of personal research on the fuel jet evolution (and self-ignition) for three fuels: diesel fuel, rape oil methyl esters (RME) and crude rape oil.

2. Research program

The investigation was carried out on a single-cylinder Diesel engine type SB 3.1 fuelled by diesel fuel, rape oil methyl esters and rape oil. The rotational engine speed was 1600 rpm

(rotational speed of maximum rotational torque), and the loading was 60 Nm (50% of M_{\max}). The control parameters and the completion of the engine were standard for diesel fuel. The propagation of atomized fuel jets in the engine cylinder, from the start of the injection to the beginning of the visible self-ignition of tested fuels, was registered. Applying the end gauge, the range and the velocity of the jet front as well as the apex angle of the injection versus the crank angle of the engine were determined for each of the tested fuels.

In addition, the start of the injection and of the self-ignition as well as the self-ignition lag for tested fuels was determined.

3. Measuring stand

The scheme of the measuring stand is presented in Fig. 1. Optical access to the combustion chamber is ensured by the endoscope. This element is connected directly with the objective of a special digital camera. High definition digital camera Pulnix CCD was used in the study. Opening time for the registration of the combustion process is 60 μ s. Maximum frequency of measuring release is 12 Hz. As the successive images are taken out from different cycles of the engine operation, the registration frequency does not directly limit the angular distance of consecutive registered expositions. Owing to this, the measuring system archives the images of the phenomena inside the engine cylinder displaced relative to each other of 0.1° OWK. Consecutive expositions are released by the signal from the optical converter of the engine AVL crank angle – Angle Encoder 364. At 720 markers placed on the converter [encoder?] disk circuit and the cooperation with the unit AVL Puls Multiplier, it ensures maximum sampling frequency to 0.05° OWK. The same signal releases simultaneously the light pulse generated in the modulus of lighting and transmitted through a light pipe to the combustion chamber in order to register the fuel injection. An important additional advantage of this measuring system is the possibility to apply the same crank angle encoder to release other kind of measures in a way entirely synchronized with filming.

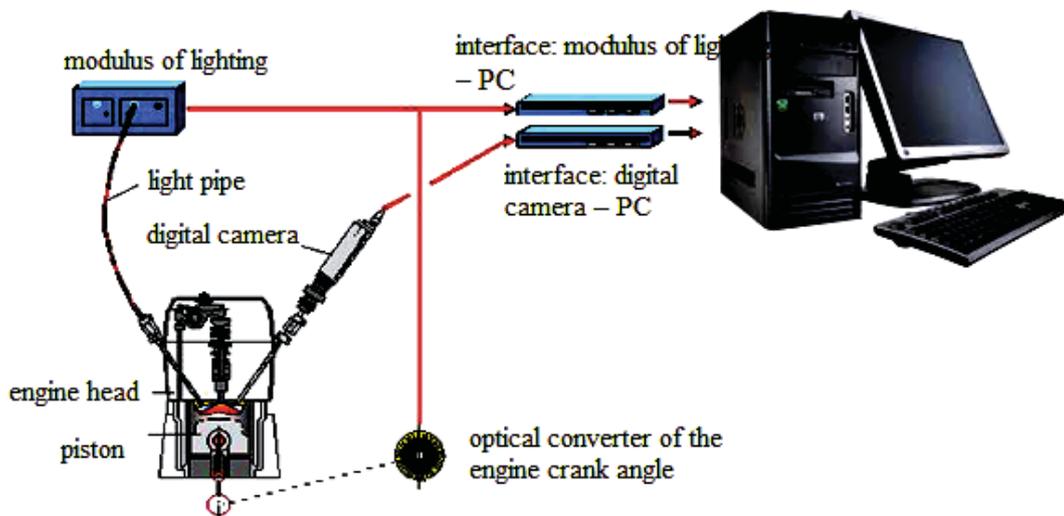


Fig. 1. Scheme of the measuring stand for the visualization of fuel injection and combustion in a diesel AVL engine VideoScope 513D [3]

Optical access to the combustion chamber is possible due to the endoscope coupled with the camera objective. Cooling of the endoscope is ensured by a forced airflow between so-called rod lenses inside the endoscope. The firm AVL offers endoscopes with diameters 7 and 4 mm. In the endoscope with 7 mm diameter (Fig. 2) the angle of view is 67° , while in the 4 mm endoscope the angle of view is 80° .



Fig. 2. a) Endoscope of the unit AVL Engine VideoScope 513D, b) Quartz shield/housing of the endoscope end

Every size of the endoscopes is available in three forms, differing by the angle between optical and geometrical axis of the endoscope. Available are the endoscopes with “direction of view” – 0, 30 and 70°.

In modern diesel engines, which heads must hold 4 valves, injector, heater plug, cooling medium channels, recirculation channels etc., it is difficult to find place for a sleeve with an endoscope and a sleeve with a pipe light source. Regarding this, the endoscopes with smaller diameter are easier in applying. However, we must remember, that the endoscopes with larger diameter and smaller angle of view need less light to achieve a correctly registered image. However, the greatest advantage of the endoscopy for filming the injection and combustion process is simplicity of adapting a mass-produced engine to measuring. Generally, this process does not differ (as to technical difficulty) from the process of adapting an engine head to the indication. Nevertheless, like in the case of preparing the head to indication, which requires the knowledge of some rules, also the endoscopy of the engine cylinder must follow its laws ensuring the correctness of registering the images inside the engine cylinder as well as their later analysis.

4. Selected properties of tested fuels

The examined fuels differ significantly regarding as well their structure and chemical composition as the values of physical parameters. Principal physical and chemical properties, important from the point of view of fuel application, are presented in Tab. 1.

It is however notable that the values of physical and chemical parameters of diesel fuel and rape oil methyl esters must follow appropriate standards, which do not apply to the natural rape oil. Striking are large scatters of these parameters values for the rape oil reported by different sources. They result from the fact that the rapeseed on the market does not derive from one, botanically determined vegetable, but, depending on the production place, it can belong to different species, or to different variety (winter or spring crops) [8]. Moreover, important factors are also climatic conditions and the way of fertilizing the culture. Physical and chemical properties depend also significantly on the technology of getting the rape oil (rape oil pressed cold or hot, extraction oil, filtered, degummed, hydrated, refined oil).

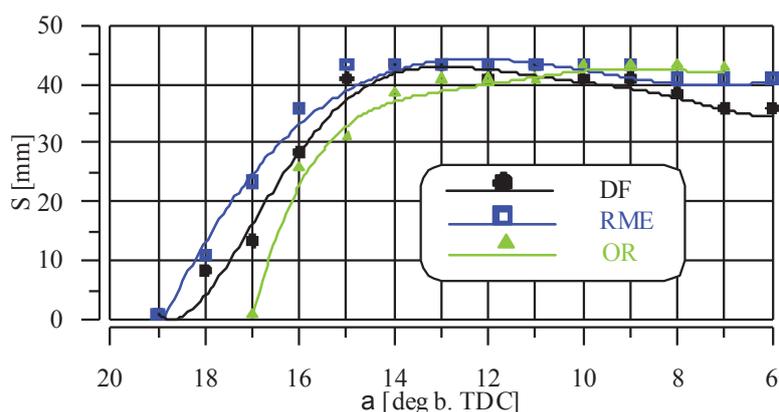
However, generally there are essential differences between the values of most parameters presented in Tab. 1 for diesel fuel and rape oil. The consequence of large triglyceride molecules is, among others, a significantly larger relative molecular mass, density and viscosity of the rape oil as compared with the diesel fuel.

5. Influence of tested fuels on the evolution of the jet injected into the engine cylinder

Presented in Fig. 7-9 photos of the jet evolution of injected fuels – diesel fuel, rape oil methyl esters and rape oil – permitted to determine the range of the jet front versus the engine crank angle. It is presented by data on Fig. 4.

Tab. 1. Physical and chemical properties of tested fuels [8]

Parameter	Fuel unit	diesel fuel	RME FAME	vegetable oil
Relative molecular mass	-	ok. 280	max. 850	max. 850
Mass density 20°C	g/cm ³	0.825	max. 0.880	max. 0.915
Kinematic viscosity 20°C	mm ² /s	ok. 4	ok. 8	max. 70
Surface tension 20°C	N/m	ok. 24 10 ⁻³	ok. 26 10 ⁻³	max. 35 10 ⁻³
Calorific value	MJ/kg MJ/dm ³	42.6 35.2	39.0 34.3	min. 38.0 min. 34.5
Average molecular composition				
- C	% mas.	87.0	77.0	77.0
- H		13.0	12.0	12.0
- O		0.0	11.0	11.0
Sulfur content	% mas.	0.3	max. 0.001	max. 0.001
Water content	mg/kg	-	max. 300	300-max 700
Free fatty acid (FFA)	% mas.	-	0.5	0.8-1.3
Cetane number	-	45-55	ok. 49	min. 40
Flash-point (ignition temperature)	K/°C	340/67	440/167	520/247
Cloud point	K/°C	266/-7	268/-5	276/3
Flow blockage of cold filter temperature	K/°C	253/-20	260/-13	285/12
Solidification point (freezing temperature)	K/°C	243/-30	252/-21	264/-9
Course of distillation				
- start		- 450/177	- 590/317	- 440/167
50%		- 535/262	- 600/327	- 545/272
- 85%	K/°C	- 595/322	- 610/337	- 595/322
Heat of vaporization	kJ/kg	230	280	max. 830
Stechiometric value	kg/kg	14.5	12.5	12.5

Fig. 4. Jet front range S as a function of crank angle for tested fuels

It is notable, that the jet range was measured in the engine cylinder at variable pressure and temperature of working factor (during the compression stroke), so, differently from the off-engine measuring [10]. Therefore, the range of the jet, after achieving a maximum value, decreased depending on the speed of vaporization of the fuel from the jet front. For diesel fuel, in the final phases of injection, the decrease of the range of liquid fuel jet front versus the engine crank angle was the highest, while for natural rape oil it was the lowest. It shows that the speed of vaporization of the fuel from the jet front was the highest. This speed was lower for RME and it was the lowest

for vegetable oil [11]. It is due to the heat of vaporization of these fuels and it leads to a different way of preparing the fuel-air mixture to the combustion. The velocity of spreading the fuel jet front just after the start of the fuel injection was the lowest for diesel fuel, a little higher for RME and the highest for vegetable oil (Fig. 5).

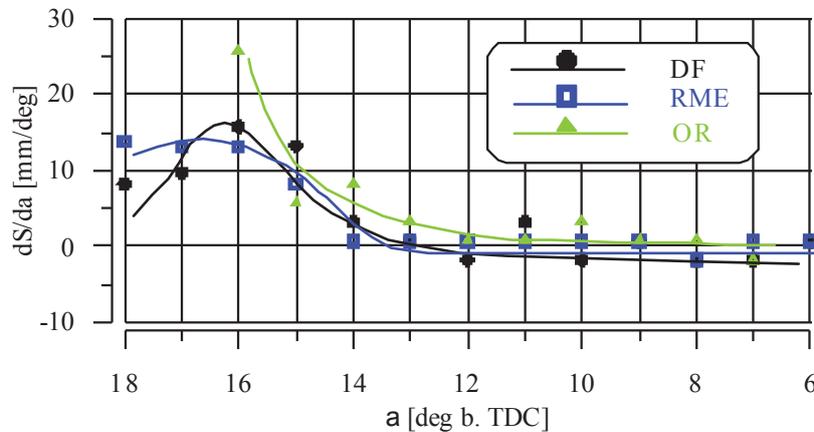


Fig. 5. Velocity dS/da of spreading the fuel jet front for tested fuels

It results both from the outflow speed variation of the fuel from the nozzle outlets and from the fact that the increase of viscosity and density of these fuels involves an increase of the drops size and mass [4, 6, 9], then, also of the kinetic energy of the drops leaving the nozzle. However, larger fuel drops are subject to higher aerodynamic drags and the spreading velocity of the fuel jet front in the case of these fuels rapidly decreases to the values similar to these of diesel fuel.

The angle of flare of the fuel jet (Fig. 6) was the largest for the rape oil, which would be advantageous for mixing the fuel with the air, as the fuel would then cover larger areas of the combustion chamber, if a worse fuel spreading had not a bad impact on the process at this moment.

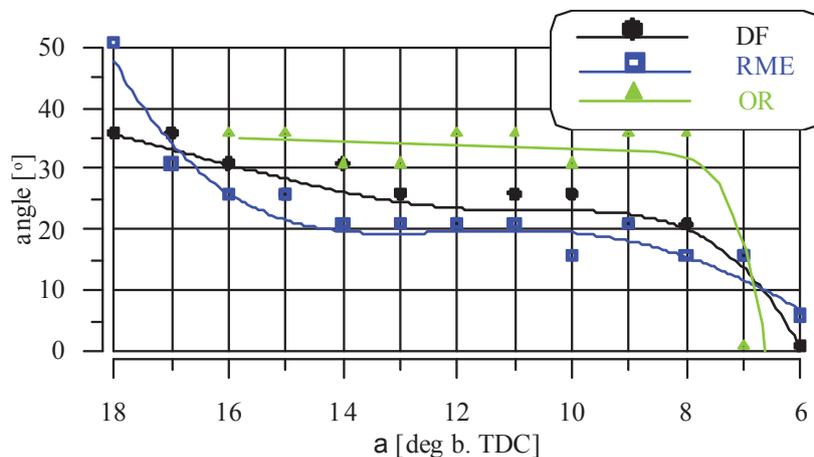


Fig. 6. Jet angle of flare for tested fuels

Characteristic for natural vegetable oil, as distinct from RME and diesel fuel, is a sensible lack of reducing the visible angle of flare of the fuel jet until the moment of self-ignition, which proves that the process of fuel spraying and vaporization gets worse, on the peripheries of the injected fuel jet as well. The change of the used fuel involved also the change of many other parameters of fuel injection. One of important parameters is the repeatability of the fuel injection [7]. The investigation performed showed that diesel fuel was characterized by a very good repeatability of fuel injection. It concerns as well the jet front range, spraying cone angle, as the shape of the fuel jet. In the case of supplying the engine with the rape oil, methyl esters, during the fuel injection, around the nucleus of the fuel jet, appeared a "cloud" of very well atomized fuel. It was favourable

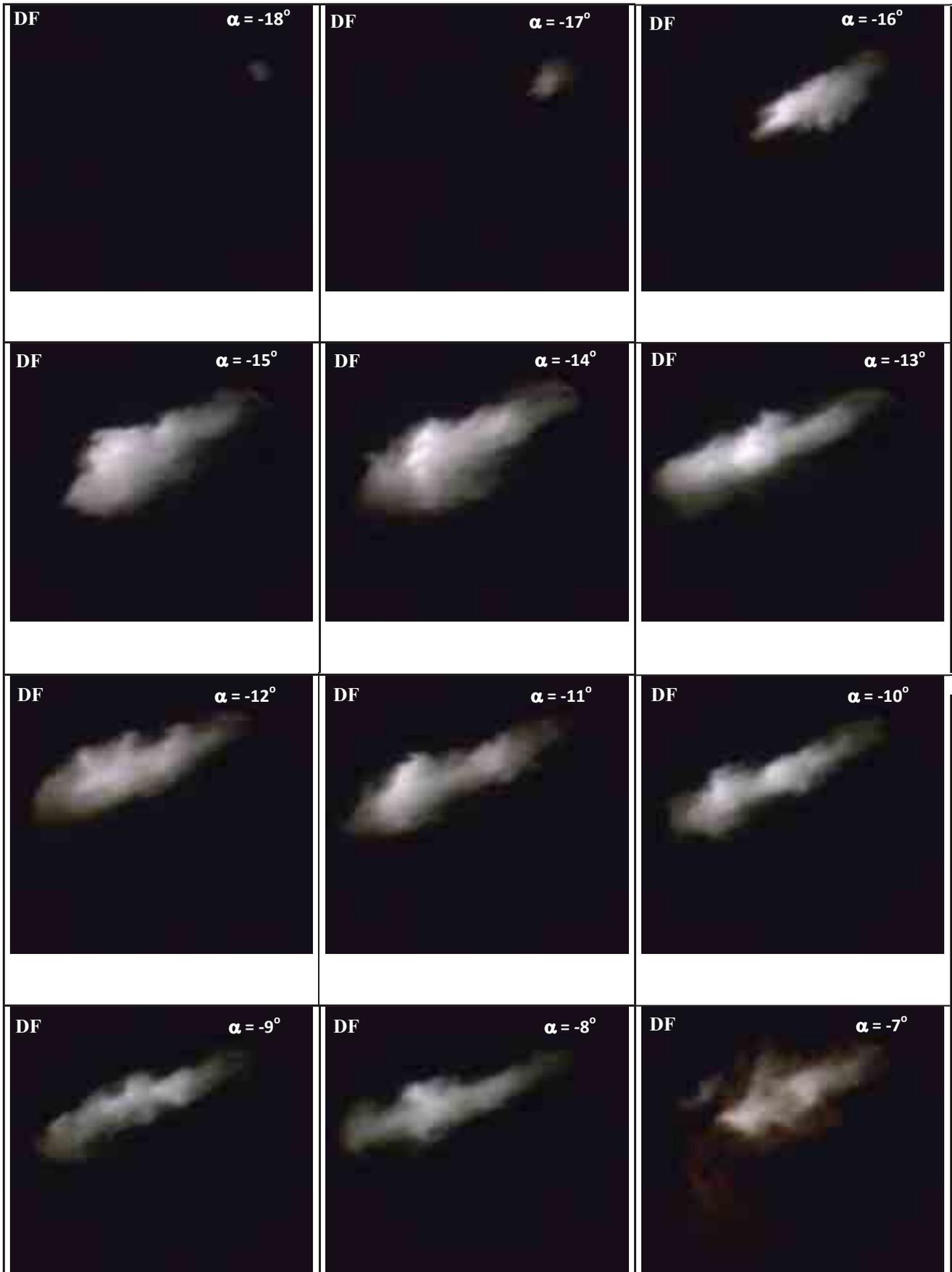


Fig. 7. Evolution of the injected fuel jet for diesel fuel DF

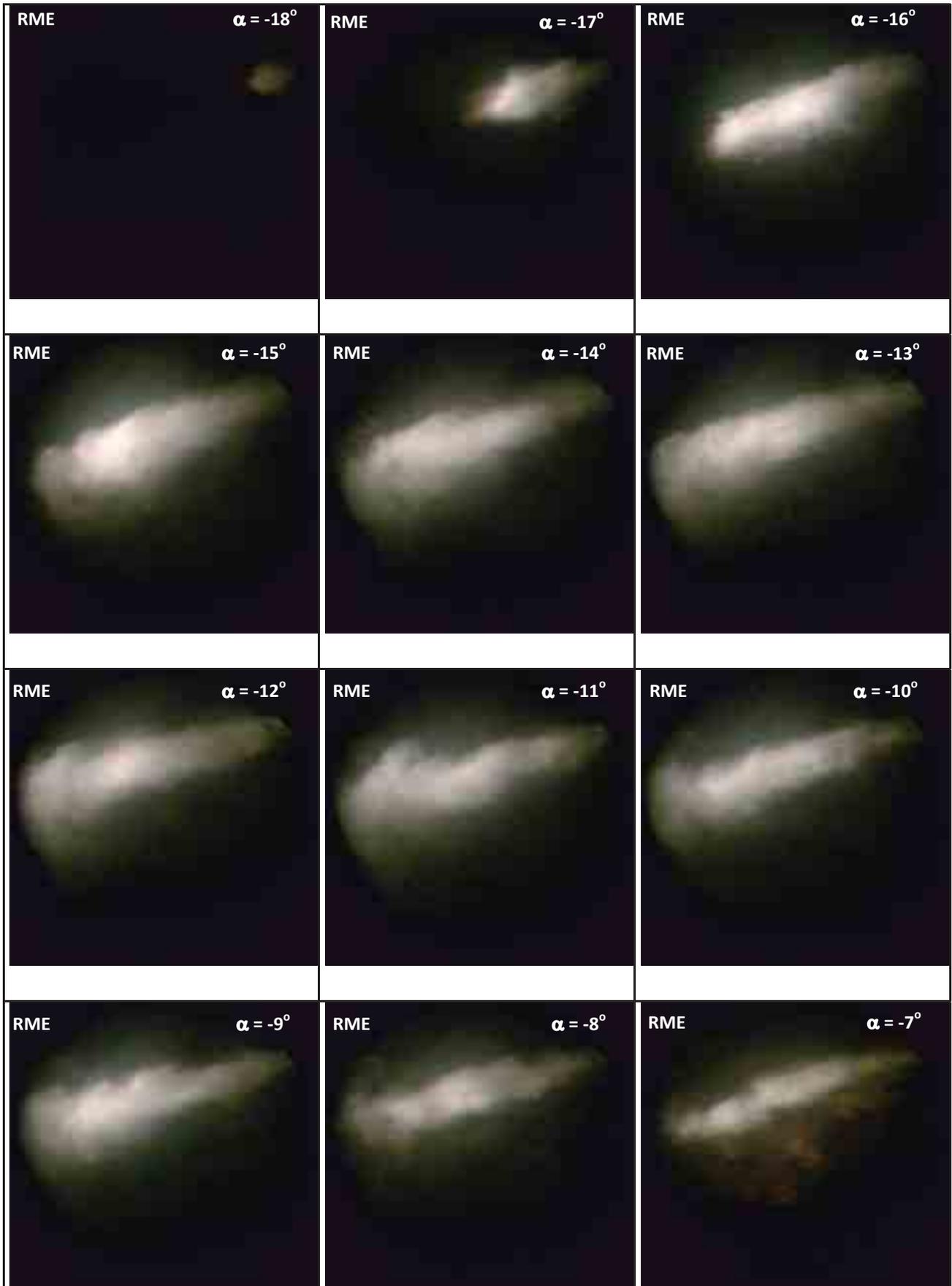


Fig. 8. Evolution of the injected fuel jet for RME

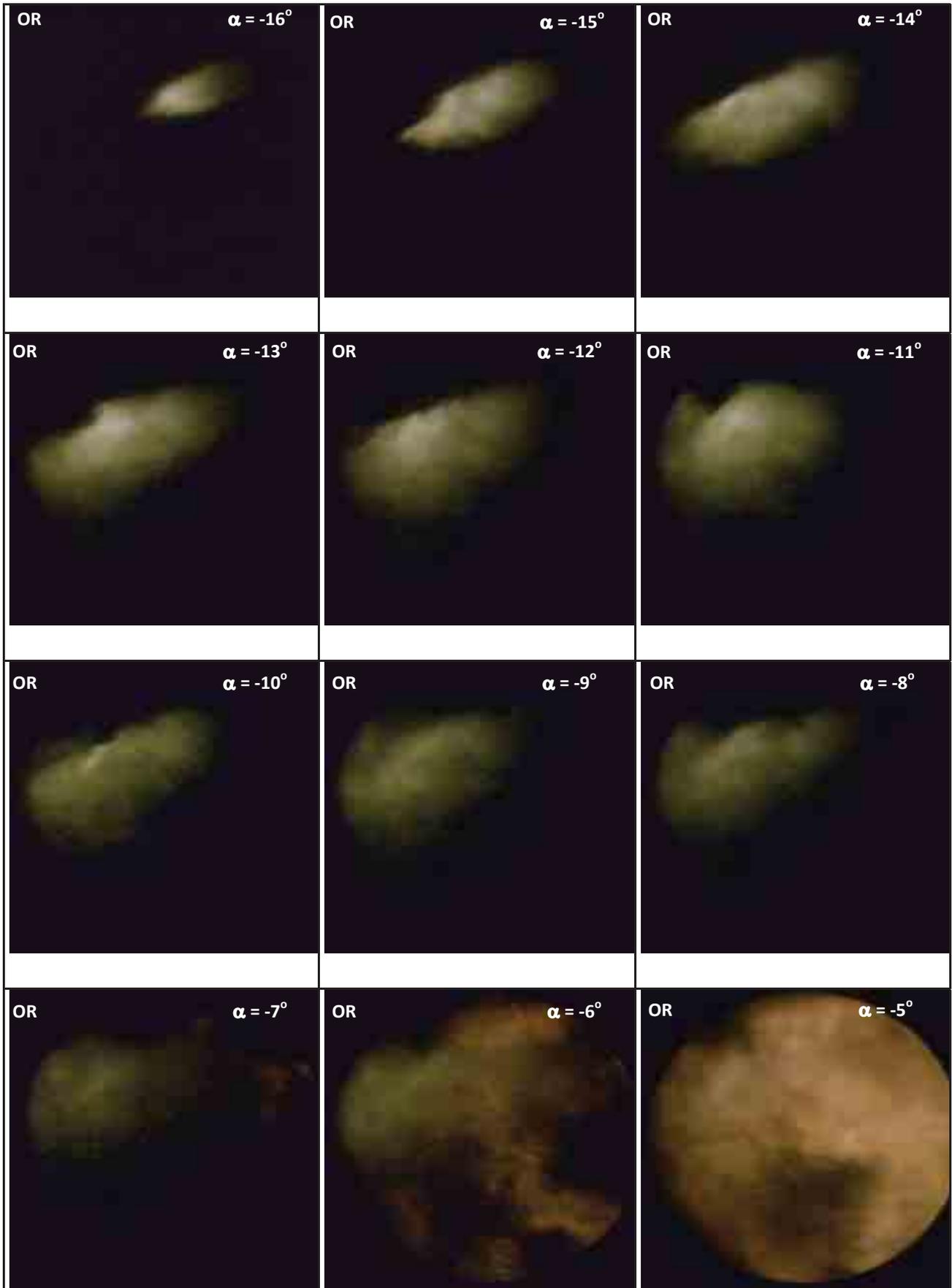


Fig. 9. Evolution of the injected fuel jet for rapeseed oil OR

for the (further) combustion with a small amount of carbon monoxide, non-burned hydrocarbons and particulate matters, as well as for a low smokiness of exhaust gases. The injection of the non-processed rape oil was characterized by a high repeatability, which, in addition to the other factors, was favourable for the increase of the amount of carbon monoxide, non-burned hydrocarbons and particulate matters in the engine exhaust gases and lowered the combustion efficiency.

6. Summary and conclusions

From the analysis of the phenomena registered on presented photos result essential conclusions concerning the injection course for tested fuels:

1. the range and the velocity of the jet front as well as the injection angle versus engine crank angle are significantly different for diesel fuel, rape oil methyl esters and natural rape oil,
2. the range of the jet front is the lowest for rape oil,
3. judging by the range of the jet front, the vaporization of rape oil drops is slower than for diesel fuel,
4. the atomization angle is the largest for the rape oil,
5. in the initial phase of the fuel injection, large and heavy drops of rape oil have higher speed than these of diesel fuel. A large surface of the rape oil drops, due to high forces of aerodynamic drag, causes a strong reduction of the spreading velocity of this fuel jet. In the final stage of the rape oil injection, its injection velocity is significantly lower than for diesel fuel.

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