**TECHNICAL UNIVERSITY OF CLUJ NAPOCA**
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# PHASE 2008

| Objectives | Activities |
|---|---|
| 2.1. The making and qualitative evaluation of the research mixtures | 2.1.1. Biodiesel-diesel oil- bioethanol researched mixtures processing |
| | 2.1.2. The analysis of physical-chemical proprieties of the made mixtures and compared them with the actually standards |
| | 2.1.3. The analysis of fuels aggressiveness regarding to elastomers |
| 2.2. The optimization of fuel injection process by numerical forming operation and simulation | 2.2.1. Models adaptation regarding the existent injection processes to the parameters of the researched fuels |
| | 2.2.2. Computerized simulation of the injection process |
| | 2.2.3. The fuel injection process parameters correlation with the burning chamber architecture |
| 2.3. The experimental making of the injected fuel spurt characteristics | 2.3.1. Adjusting and preparation of the research equipment |
| | 2.3.2. The analysis of the main fuel injection parameters on the testing stall |
| | 2.3.3. The correlation by experimental research of fuel injection parameters with the theoretical results |
| | 2.3.4. Processing and evaluating of the experimental result. Validating of the results |

## 2.1. The making and qualitative evaluation of the research mixtures

### *2.1.1. Biodiesel-diesel oil- bioethanol researched mixtures processing*

The ten kinds of fuels identified in the previous phase, for making the object of this phase research, are shown in table 2.2 and were made in the similar way like previous phase (miscibility study). The reference for this research was diesel oil.

### *2.1.2. The analysis of physical-chemical proprieties of the made mixtures and compared them with the actually standards*

The physical-chemical proprieties for those eleven fuels were: density, kinematical and dynamic sliminess, surface tension, water content, sulfur content, flash, filtering capacity and disturbance temperatures. The used apparatuses for physical-chemical proprieties analysis of the mixtures is presented in table 2.1. Some experimental results obtained are shown in table 2.1 and figure 2.1 and 2.2.

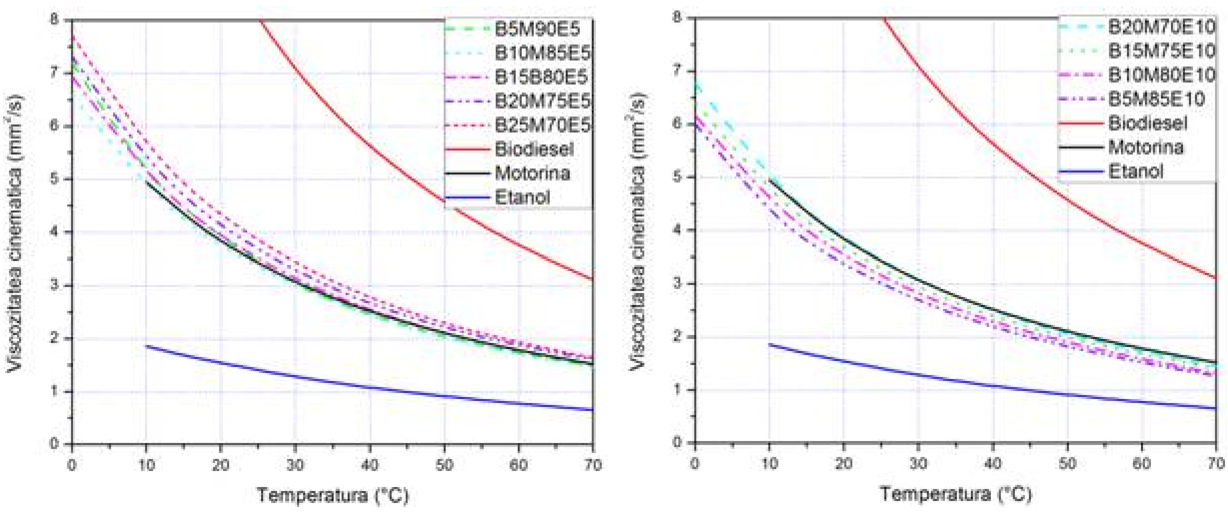



**Fig.2.1.** Kinematical sliminess of research mixtures compared with constituents slimness.

**Table 2.1.**The used apparatuses for physical-chemical proprieties analysis of the mixtures biofuels components

| Measure measured | Apparatuses | Producer | Analysis method | Obtained results |
|---|---|---|---|---|
| *0* | *1* | *2* | *3* | *4* |
| Density | SVM 3000 Stabinger | Anton Paar GmbH, Austria | SR EN ISO 12185 (pendulum U pipe method) | 11 variation curves |
| kinematical and dynamic sliminess | | | ASTM D 7042-04 | 22 variation curves |
| The main characteristics of diesel oil | IROX 2000 DIESEL | GRABNER INSTRUMENTS, Austria | ▪ EN/DIN 22719<br>▪ cetane number – ASTM D 613<br>▪ cetane index – SR EN ISO 4264, ASTM D 976<br>▪ aromatic polycyclic hydrocarbon content – EN 12916<br>▪ EMAG content – EN14078<br>▪ distilling proprieties: $t_{85}$, $t_{90}$, $t_{95}$ (EN ISO 3405, ASTM D 86) | 66 measurements |
| sulfur content | ANTEK 9000 | PAC, USA | Piro chemiluminescence's, \| ASTM D 5453 | 11 measurements |
| Minimal flash temperature | HFP 339 Pensky-Martens | Herzog, USA | EN/DIN 2719 | 22 measurements |
| Water content | Predicta OM 1000, Model CA21 | A1-envirotech, England | titration Coulometer Karl-Fischer, EN ISO 12937 | 11 measurements |
| Cetanic value | ZX-101XL | ZELTEX, USA | Closed infrared | 22 measurements |
| Minimal filtering capacity temperature | FPP 5Gs | ISL, France | SR EN 116 | 11 measurements |

### *2.1.3. The analysis of fuels aggressiveness regarding to elastomers*

For the analysis of research fuels aggressiveness it has been chosen a series of seals elements, which are part on a fuel charging system structure on a MAC. The seals elements, hereupon to begin with weight measurement, physical dimension, volume and hardness were introduced in eleven glass vessel which contained fuels presented in table 2.2. By the ten months time (December 2007 - October 2008) samples were re-examined bimonthly. In this period of time on did not see substantial change regarding the follows parameters.

**Table 2.2.** The research mixtures and some of their determined proprieties

| No. | Mixture | Fuel code | Biofuels, % (v/v) | Kinematical sliminess, $mm^2/s$ | Surface tension N/m | Cetanic value | Density, $kg/dm^3$ |
|---|---|---|---|---|---|---|---|
| 1 | BME(2) | B25M70E5 | 30 | 2.7560 | 0.0285 | 52.60 | 0.852 |
| 2 | BME(4) | B20M70E10 | 30 | 2.4796 | 0.02937 | 49.70 | 0.847 |
| 3 | BME(5) | B20M75E5 | 25 | 2.6447 | 0.03285 | 51.85 | 0.850 |
| 4 | BME(8) | B15M75E10 | 25 | 2.3739 | 0.03465 | 48.95 | 0.845 |
| 5 | BME(9) | B15M80E5 | 20 | 2.5269 | 0.03476 | 51.10 | 0.847 |
| 6 | BME(13) | B10M80E10 | 20 | 2.2746 | 0.03176 | 48.20 | 0.843 |
| 7 | BME(14) | B10M85E5 | 15 | 2.4205 | 0.03483 | 50.35 | 0.845 |
| 8 | BME(19) | B5M85E10 | 15 | 2.1759 | 0.03065 | 47.45 | 0.843 |
| 9 | BME(20) | B5M90E5 | 10 | 2.4353 | 0.03461 | 49.60 | 0.841 |
| 10 | BME(27) | M95E5 | 5 | 2.2390 | 0.03322 | 48.85 | 0.841 |
| 11 | BME(28) | M100 | 0 | 2.4853 | 0.02900 | 51.00 | 0.843 |

| No. | Mixture | Fuel code | sulfur content, mg/kg | Water content, mg/kg | Flash temperature, °C | Minimal filtering capacity temperature, °C | Caloric power, MJ | Equivalent factor |
|---|---|---|---|---|---|---|---|---|
| 1 | BME(2) | B25M70E5 | 8.578 | 594.8 | 18 | -3 | 41.10 | 0.96 |
| 2 | BME(4) | B20M70E10 | 7.912 | 629.8 | 16 | -3 | 40.45 | 0.95 |
| 3 | BME(5) | B20M75E5 | 8.171 | 520.5 | 17 | -3 | 41.24 | 0.97 |
| 4 | BME(8) | B15M75E10 | 7.504 | 555.5 | 15.5 | -3 | 40.59 | 0.95 |
| 5 | BME(9) | B15M80E5 | 7.764 | 446.2 | 16 | -3 | 41.38 | 0.97 |
| 6 | BME(13) | B10M80E10 | 7.097 | 481.2 | 15 | -3 | 40.74 | 0.96 |
| 7 | BME(14) | B10M85E5 | 7.356 | 371.9 | 14 | -3 | 41.53 | 0.97 |
| 8 | BME(19) | B5M85E10 | 6.689 | 406.9 | 15 | -3 | 40.88 | 0.96 |
| 9 | BME(20) | B5M90E5 | 6.949 | 297.6 | 17.5 | -3 | 41.67 | 0.98 |
| 10 | BME(27) | M95E5 | 6.541 | 223.3 | 14 | -3 | 41.81 | 0.98 |
| 11 | BME(28) | M100 | 6.800 | 114.0 | 69 | 0 | 42.60 | 1.00 |

## 2.2. The optimization of fuel injection process by numerical forming operation and simulation

### *2.2.1. Models adaptation regarding the existent injection processes to the parameters of the researched fuels*

The injection process has the main function over an internal combustion engine performance (power, economics and pollution emission). Fuel injection shaping suppose knowing entrance parameters: *maximum flow capacity through spraying opening; injection pressure; burning chamber pressure; fuel physical proprieties; geometrical elements of spraying opening* and follows the analysis of exiting parameters: *injector flow factor (injector spraying opening); dispersion angle of fuel spurt; actually speed of injected fuel; spurt penetration; drops diameters*. The obtained values, base on a mathematical model developed, for *injection speeds, fuel spurt cone angle and medium diameter of fuel drop* are presented in table 2.3, which shows also the influence of injection pressure over injection speeds and injected fuel drop diameter.

**Table 2.3.**Parameters values for the research fuels

| **Injection pressure,** [bar] | **Density,** [kg/m$^3$] | **Injection speed,** [m/s] | **Cone angle,** [$^0$] | **SMD** (Sauter medium diameter), [cm] |
|---|---|---|---|---|
| **Diesel oil** | | | | |
| 300 | 841 | 171.575 | 11.34 | 0.055 |
| 500 | | 251.803 | 13.74 | 0.048 |
| 900 | | 312.044 | 15.03 | 0.044 |
| 1200 | | 362.406 | 16.49 | 0.041 |
| **Biodiesel** | | | | |
| 300 | 886 | 167.161 | 11.34 | 0.056 |
| 500 | | 245.325 | 13.74 | 0.048 |
| 900 | | 304.016 | 15.30 | 0.045 |
| 1200 | | 353.083 | 16.49 | 0.042 |
| **B20M70E10** | | | | |
| 300 | 846 | 171.067 | 11.34 | 0.057 |
| 500 | | 251.057 | 13.74 | 0.049 |
| 900 | | 311.12 | 15.3 | 0.044 |
| 1200 | | 361.333 | 16.49 | 0.042 |
| **B20M75E5** | | | | |
| 300 | 848 | 170.865 | 11.34 | 0.057 |
| 500 | | 250.761 | 13.74 | 0.050 |
| 900 | | 310.753 | 15.3 | 0.045 |
| 1200 | | 360.907 | 16.49 | 0.042 |
| **B25M70E5** | | | | |
| 300 | 851 | 170.563 | 11.34 | 0.058 |
| 500 | | 250.319 | 13.74 | 0.050 |
| 900 | | 310.205 | 15.3 | 0.046 |
| 1200 | | 360.27 | 16.49 | 0.043 |

For the factitious fuels have considered following proprieties: *vaporization latent heat, thermal conductivity, density, steam pressure, surface tension and sliminess* for temperatures between 0…730 K, reference made to used values by KIVA for diesel oil and ethanol. The values and the variation of all studies proprieties are graphic presented, similar with figure 2.3.

### *2.2.2. Computerized simulation of the injection process*

The simulation environment chooses was KIVA 3V, software developed by the Los Alamos National Laboratory and Engine Research Center for Wisconsin University-Madison USA. The application works in MS-Dos and Linux operation system, being in the main created for the study of thermodynamic and chemical processes of the internal combustion engine. The criterions which guide to use of this software were mainly the availability of the software, this kind of software being free and also the operation system under which works (Linux) being also free. Beside this criterion are also the possibilities of using different fuels, easiness for defining entrance parameters and last but not least program characteristics, which allow shaping and simulation 2D and 3D, especially for the internal combustion engine. For the simulation environment was necessary an adaptation of this software to the studied problem by the changing the fuels library.

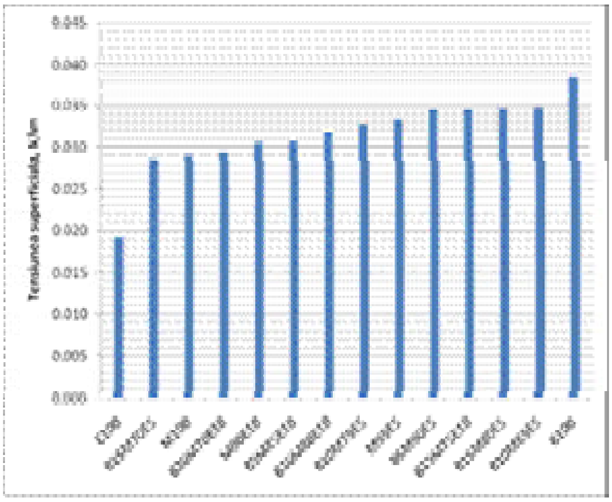



**Fig. 2.2.** Mixtures surface tensions.

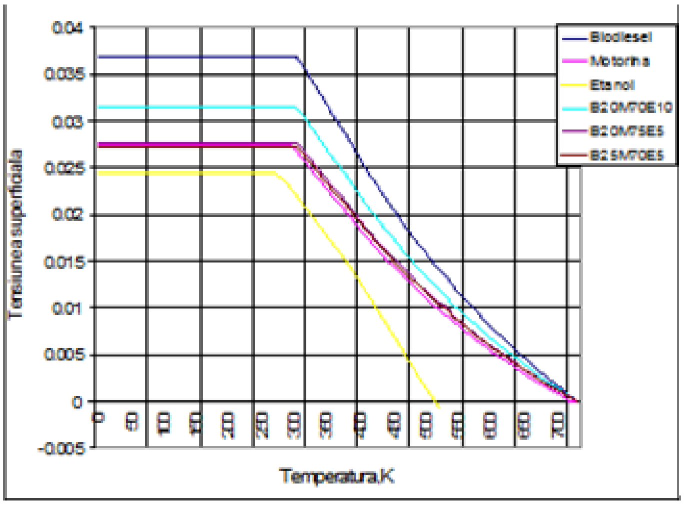



**Fig. 2.3.** Surface tension variation for bio-diesel, diesel oil, ethanol and mixtures biodiesel-diesel oil- bioethanol

For the possibility of making a comparatively study between spurts were made five different simulation sets, for each kind of fuel (tab. 2.4.). The obtained results after computerized simulation were processed, and the obtained results were playable. Where the case, entrance data were corrected, and the simulation was made again. Few examples from the obtained imagines after simulation and post processing for those five kinds of fuels at injection pressure of 50 MPa, ambient pressure was 1MPa and the ambient temperature was 300 K is shown in table 2.4.

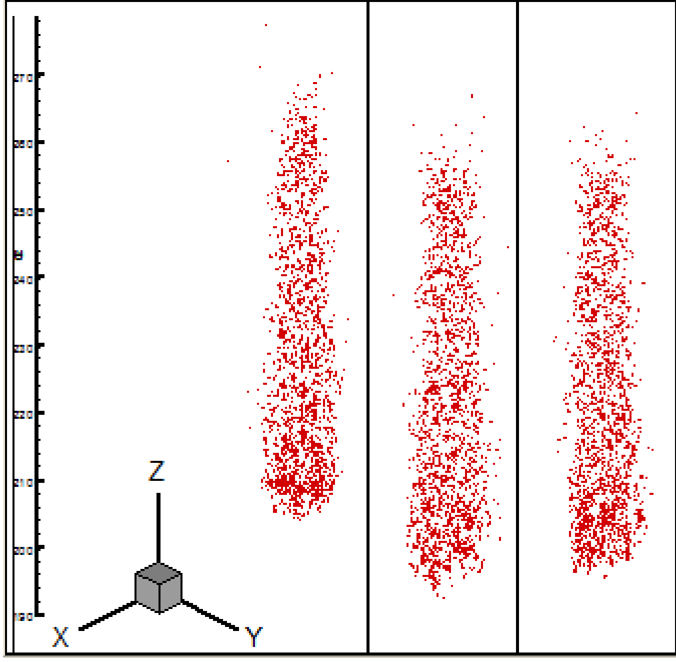
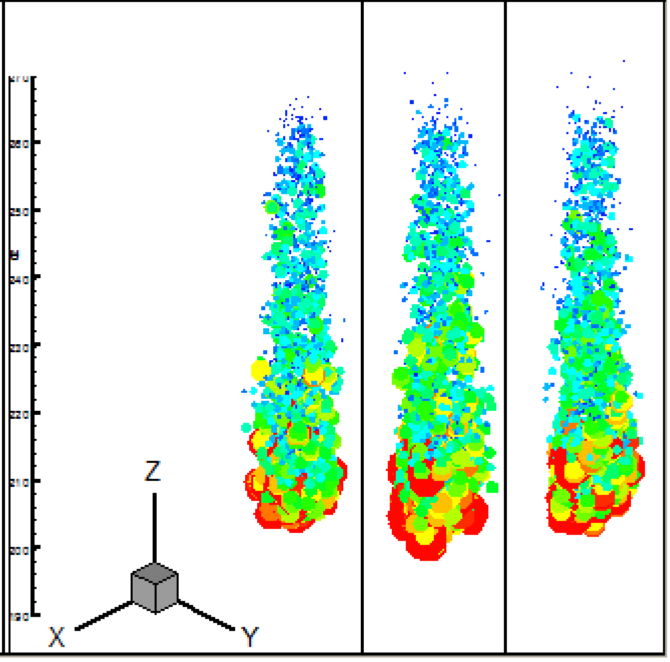
### *2.2.3. The fuel injection process parameters correlation with the burning chamber architecture*

As part of *preprocessing* were defined more parameters by whose use is shown the medium in which the simulation is made. For the chosen model, were defined: cylinder diameter, stoke, and "squish", chosen as well as to show the case of free air injection. Geometrical model of burning chamber was made by a hexahedron networks, whose dimension varying and are defined in the inside of domains. By the temporal discrimination are assigned the simulation moments and upper limits of the time step. The time step value is analysis at each simulation cycle, following the imposed restrictions in which $\Delta t_{mx}=10^{-5}$ s and $\Delta t_{mxca}=0.5$ °RAC.

*The processing* was the compilation and rolling of KIVA 3V software for each case presented in table 2.3.

For the *after processing* of simulation obtained data on use Tec Plot V.7 program in which were loaded exiting folders from KIVA, and after a further processing on obtained the shape of fuel spurt. Fuel spurts leakage is graphical shown at 5, 15, 25 and 30 °RAC (Table 2.3) with the purpose of prominence of differences between spurt characteristics of diesel oil, biodiesel and simulated mixtures. Obtained results examples in case of a four spraying openings are shown in figure 2.4.

**Table 2.4.** Examples of obtained imagines after injection simulation process

| Injection simulation results for research fuels (at 3.0 ms) | | | Fuel spurt evolution on the way of injection process (at 3.0 ms) | | |
|---|---|---|---|---|---|
| **Diesel oil** | **Biodiesel** | **B25M70E5** | **Diesel oil** | **Biodiesel** | **B25M70E5** |
|  | | |  | | |

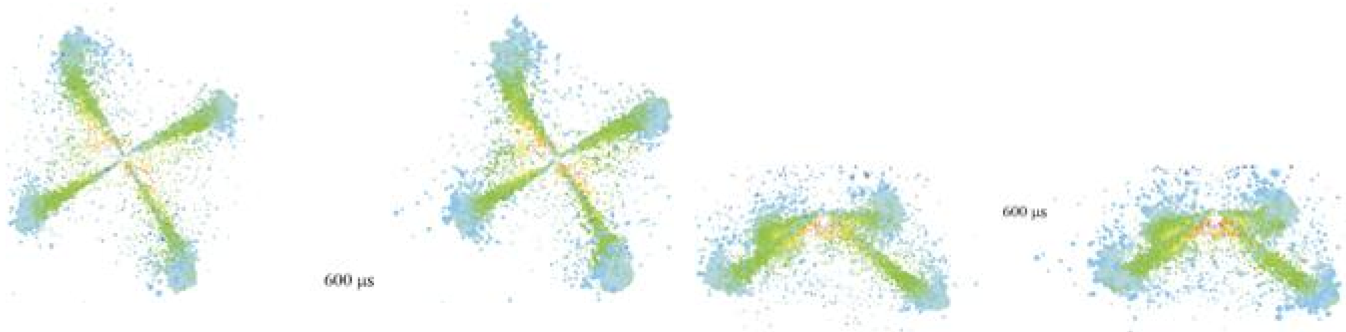
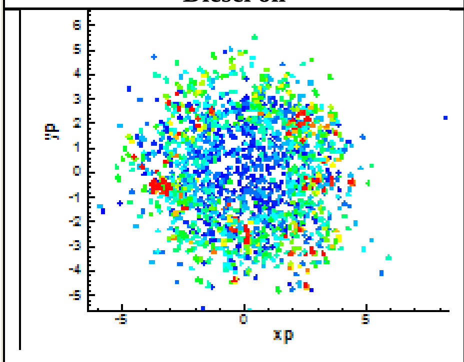
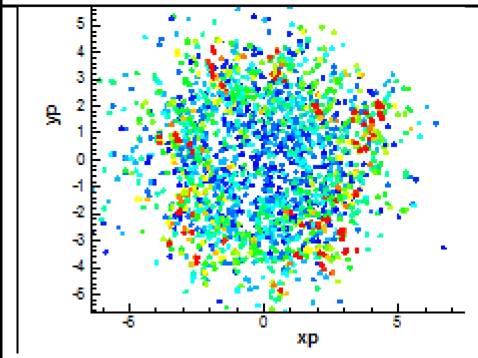
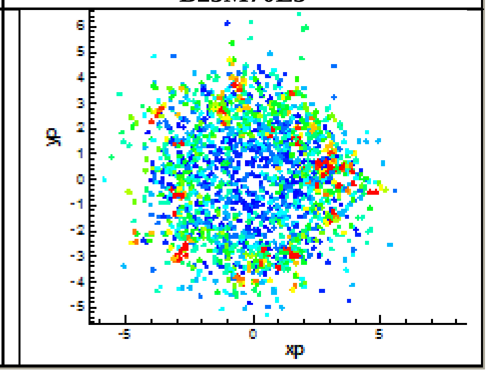



**Fig. 2.4.** The correlation between injection process parameters and burning chamber shape.

**Table2.3.** Fuel spurt dispersion, at 30 RAC

| **Diesel oil** | **Biodiesel** | **B25M70E5** |
|---|---|---|
|  |  |  |

## 2.3. The experimental making of the injected fuel spurt characteristics

### *2.3.1. Adjusting and preparation of the research equipment*

For the experimental making of fuel spurt characteristics was conceive and realized a professional experimental stall (Fig. 2.5), which allows the making off some sets of photography in the successive stages of fuel spurt development.

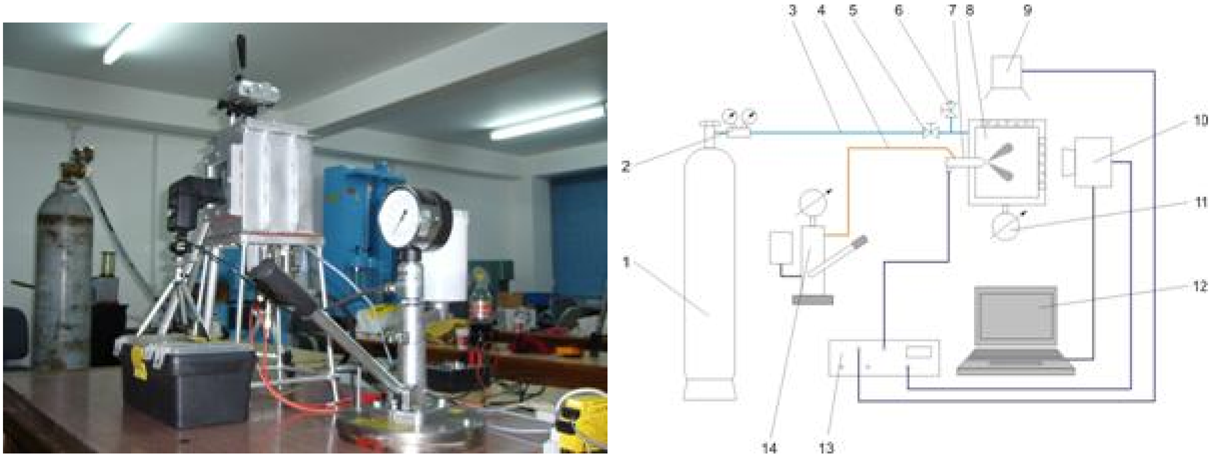



**Fig. 2.5.**Experimental stall for injection process study: *1 – inert gas cylinder ($N_2$), 2 – pressure regulation valve, 3 – high pressure hose, 4 – fuel pipe, 5 –pressure faucet, 6 –blow faucet, 7 –electromagnetic injector, 8 –pressure chamber, 9 –flash-gun, 10 – camera, 11 –pressure sensor, 12 – laptop, 13 – timing unit, 14 – hand fuel pomp.*

### *2.3.2. The analysis of the main fuel injection parameters on the testing stall*

For this it been use a long exposure time (2s), and the flash-gun starts with a delay for the beginning of injection (Fig. 2.6). Experimental conditions were: injection pressure 50 MPa, pressure from pressure chamber 1 MPa, environment temperature 300 K.

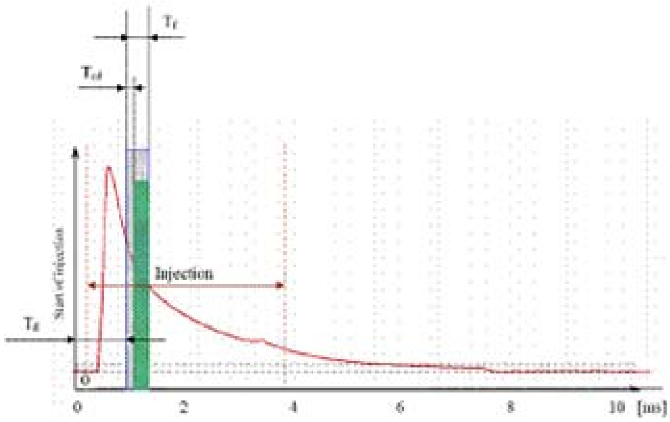



**Fig. 2.6.** Photo shot achievements:
*$T_{cd}$ – photo shot delay; $T_f$ – illumination time;*
*$T_d$ – delay between injection beginning and flash-gun start.*

### *2.3.3. The correlation by experimental research of fuel injection parameters with the theoretical results*

For the correlation between experimental research and theoretical ones it follows the assuring of identically condition regarding the injection process evolution, such as the obtained results to be as much as possible close. On the period of research phase evolution the shaping and simulation process was restarted as much as it impose this thing for assuring the concordance between theoretical results and experimental ones.

### *2.3.4. Processing and evaluating of the experimental result. Validating of the results*

By processing of imagines obtained with professional programs help on establish: spurt penetration, injection cone angle (Fig. 2.8), spurt speed and disintegration time. Experimental results were compared with theoretical ones, and the last ones were validated in proportion of 90%.

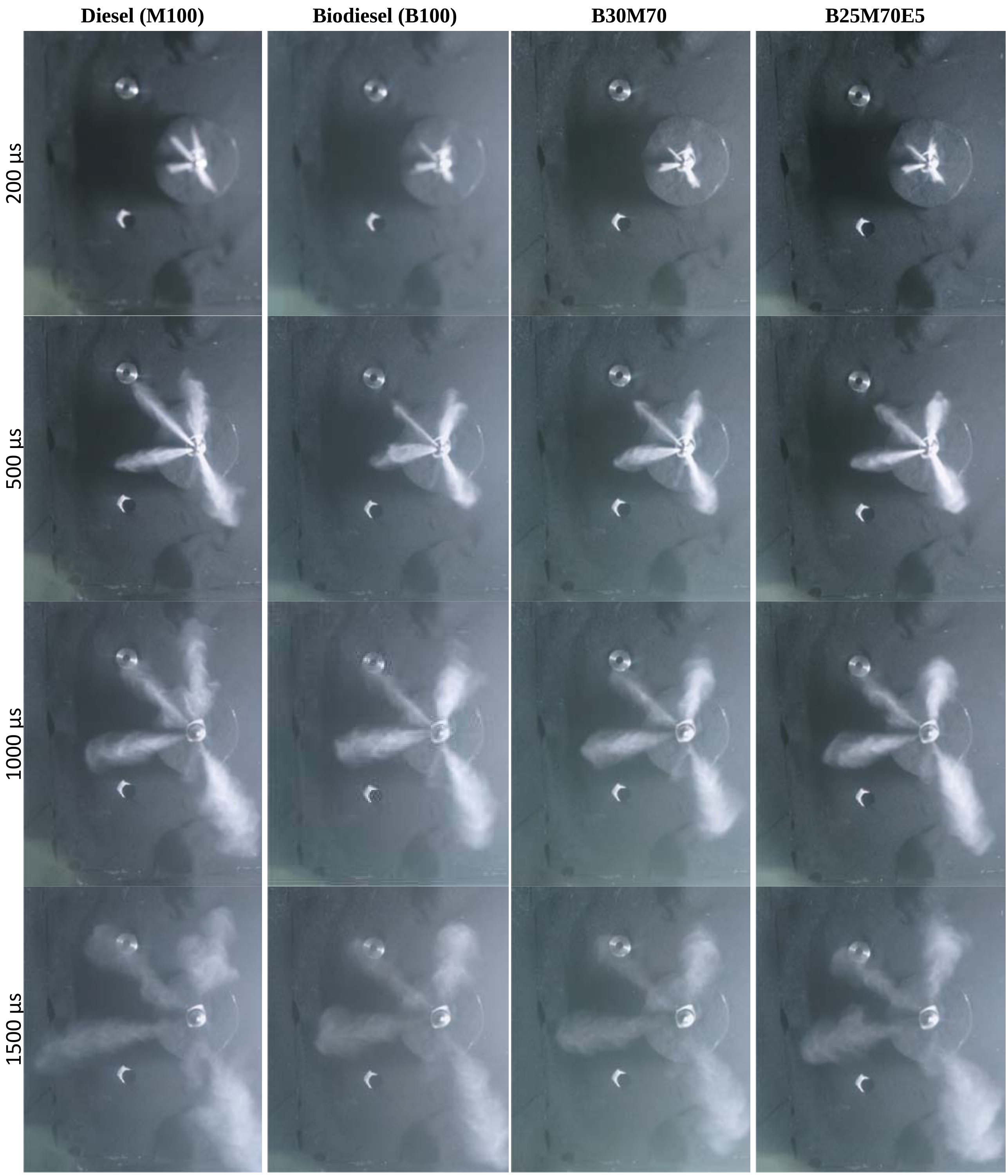



**Fig. 2.7.**The obtained imagines for diesel oil (M100), biodiesel (B100), biodiesel-diesel oil mixture (B30M70) and biodiesel-diesel oil-bioethanol (B25M70E5).

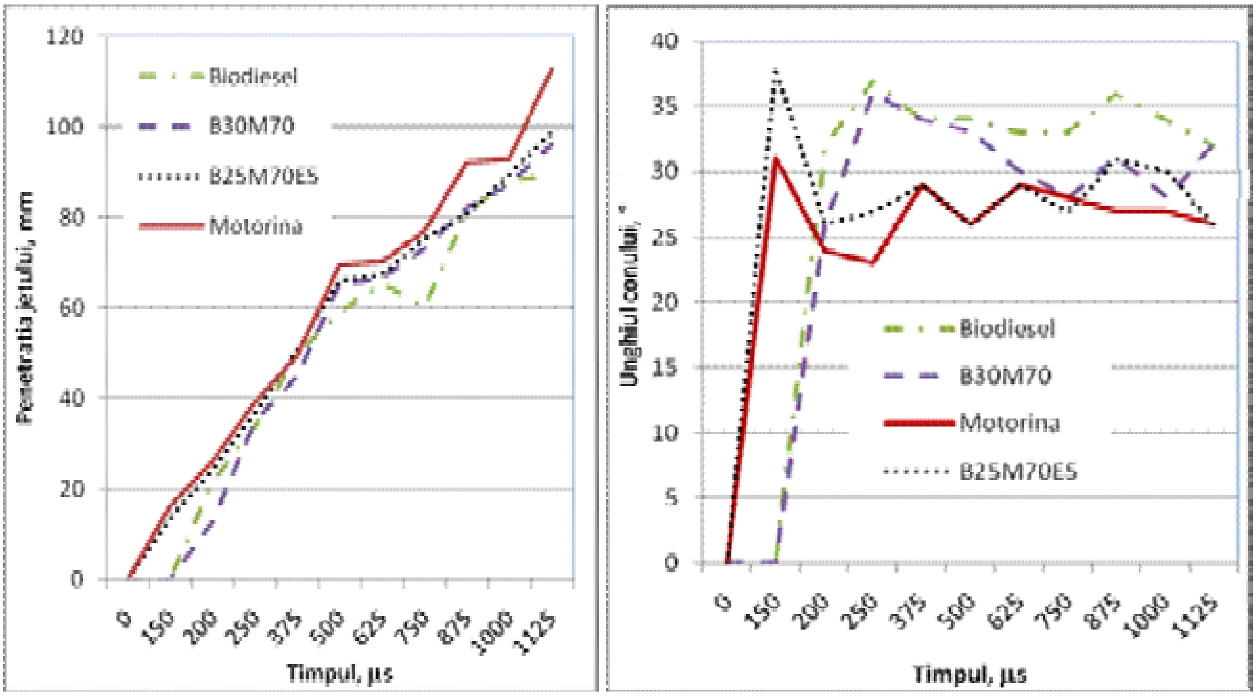



**Fig. 2.8.** Spurt penetration and injection cone angle.

***Conclusions:***

– Regarding physical proprieties: most of the physical proprieties of the mixtures biodiesel-diesel oil-bioethanol are close to those of diesel oil; from the point of view of sliminess the most close values are obtained for the mixtures with a biodiesel content two times higher than ethanol one; the mixtures density rise with the rise of biodiesel content, but they have a lower density that ethanol; caloric power lower easily especially with the ethanol content rise; ethanol lower cetanic value is compensated by the higher cetanic value of biodiesel;

– Regarding the fuel research shaping on can say the followings: the fuel research shaping by the variation with temperature of physical proprieties, which influenced the injection process unfolding (vaporization latent heat, thermal conductivity, density, steam pressure, sliminess etc.) it take place with an adequate approximation, comparable with diesel oil one, which model exist in the used software library;

– Regarding the injection process simulation on find out the followings: with the rise of injection pressure rise also the injection speeds, same the angle which is form by the spurt cone; the medium particle diameter lower (but it depends on fuel density); the biodiesel dispersion spurt is higher than other case dispersion spurt; the vaporization of the particles for fuels with higher ethanol content, is faster; spurt cone angle vary function of fuel type, higher one being in case of biodiesel, than the mixture with higher content of ethanol B20M70E10, following in the decreasing order B20M75E5 and B25M70E5; the spurts shape for the mixtures which contained ethanol is closer to diesel oil shape;

– Regarding the tests on stall, the recording imagines in the consecutive phases of the injection process shows that mixture B25M70E5 is closer very much to diesel oil, proving out the theoretical results obtained by simulation.

– Due to fact that mixture B25M70E5 lead to the closer results with ones obtained in diesel oil case, future research shall concentrate on this.