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The comparative study of the influence of the parameters of the technological process of abrasive flow machining of the nozzle holes of the fuel injectors on the performance of the injection system

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Abstract. Improving the performance of automobiles is achieved by ensuring the optimal spraying characteristics of the mixture in the combustion chamber, which is achieved by changing the geometric parameters of the fuel flow of the fuel fluid through the nozzle. To obtain good energy performance of thermal engines in order to reduce pollution, it is used as processing operation (finishing and rounding) of the entrance to the fuel injector nozzle hole, erosion processing. Hydroerosion processing is carried out by removing the material to the erosive particles that are suspended in a working fluid, as a carrier.
From the analysis of this process it follows that the reduction of cavitation, the rounding of the nozzle inlet can reduce the wear caused by the diesel flow when the injection system is in operation and implicitly the reduction of the impact of pollution on the environment.

Keywords: spraying; flow; abrasive; fluid; pollution

1. Introduction

In recent times, global warming and high levels of pollution have led car manufacturers to invest in design, improving the manufacture of thermal engines in order to reduce pollution emissions and energy efficiency.

The main subsystem that can significantly influence the quality of fuel mixing in the combustion chamber is the injection system that can lead to increased energy efficiency and reduced pollutant compounds.

Given that diesel engines operate at high pressures, the design of the injection equipment is difficult in order to ensure the increase of the homogenization of the fuel mixture respectively air and fuel in the combustion chamber in order to provide greater efficiency and reduced pollutants.

Over time, an important role in a proper mixing is played by the quality of the fluid flow upstream of the nozzle orifice and the cavitation effect that occurs in the area of entry into the fuel nozzle orifice due to the sharp edge that achieves a deflection of the spray process, causing the coefficient to decrease discharge and an improper fuel mixture.

At the entrance to the nozzle hole during the injection process, cavitation can occur all the time, as shown in figure 1.

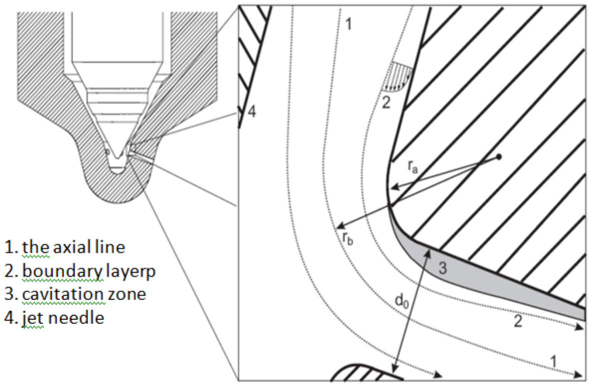

Figure 1. Cavitation phenomenon in the nozzle inlet area[1]

Cavitation can be influenced by the variation of the flow section [2], it will increase with the increase in pressure [3], for which a hydro-abrasive processing can be used to shape the edges, to reduce the influence of cavitation and obtain a coefficient of high discharge.
Hydro-abrasive machining has proven in recent years to be useful for machining automotive fuel injectors to improve fuel flow. Figure 2 shows the behavior of the fluid flow after hydro-erosive grinding and rounding of the sharp edges at the entrance to the flow hole of the injector nozzle.

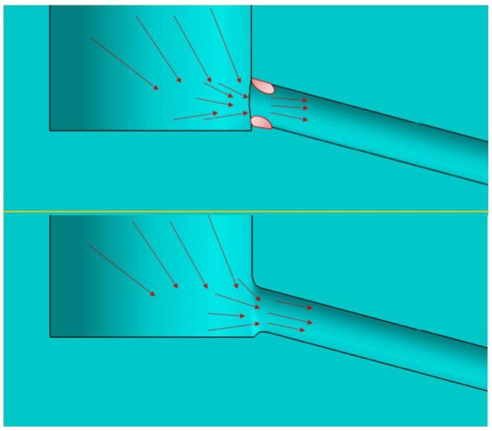

Figure 2. Behavior of fluid flow lines before and after hydro-erosive grinding [4]

Figure 2 shows the flow lines of the fluid before and after the hydro-erosive grinding effect of the inlet edges in the injector nozzle channel.

The main effects of cavitation are:

-blocking the flow of the flow lines through the nozzle holes due to the bubbles that form due to cavitation, a fact that implies a smaller flow surface;

- the noise produced by bubbles forming and collapsing;
- causes erosion of the inner surfaces of the nozzle orifice.

The spray tip velocity is higher for the nozzle that has a rounded inlet edge versus a sharp one [5]. Rounding also reduces the effect of cavitation [6].
Sharp edge rounding is achieved by passing an erosive fluid through the injection channels [7] and contains high hardness particles that are suspended in a fluid that has a low viscosity. Particles with low density determine a low friction coefficient of the surface and a higher jet speed [8].

The temperature has a critical effect, namely with the increase in temperature the viscosity of the medium decreases [9].
The particulate matter fluid is forced to flow against the walls of the channel with pressures up to 100 bar, causing by the impact of the abrasive particles the removal of the material from the areas of sudden transition of the erosive flow, until the specified flow rate is reached.

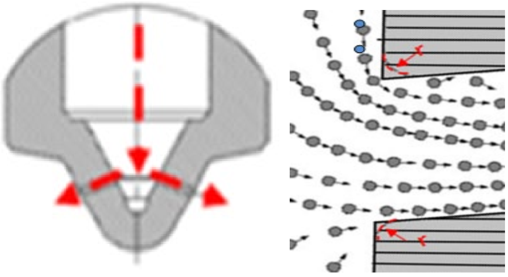

Figure 3. Scheme of the erosive fluid flow through the injection channels

Rounding is defined as the ratio of the volumetric flow rate increase after rounding to the volumetric flow rate before it [10].

2. Analysis of the variation of the parameters of the hydro-abrasive processing of the fuel nozzles using the abrasive fluid

In the experimental study, we analyzed the variation of the injection time and speed for one liter of abrasive liquid for different sizes of the abrasive microgranules, different concentrations of the abrasive medium and the variation of the pressure entering the fuel nozzle (extrusion pressure) up to the pressure of 80 bars.

The main experimental parameters of the abrasive flow machining process are:

a) Constructive parameters of the nozzle:
- nozzle hole diameter   d= 0,24 mm
- the length of the nozzle hole   L= 1,1 mm
- the number of injection holes   n=5

b) abrasive environment:
    b1)- calibration fluid for diesel injection equipment ISO 4113:2010
        kinematic viscosity   2.53 mm²/s
        density -   ρ=0.825 g/ml
    b2) abrasive granules
        Silicon carbide   5 µm   7 µm
c) abrasive flow machining setup parameters
    c1) Inlet pressure   30 bar   80 bar
    c2) granulation of abrasive particles   5 µm   7 µm
    c3) Variable volume fraction   0,1   0.2
d) the amount of working fluid   1L

Abrasive powders and calibration fluid for diesel injection equipment will be used for the experiment. In order to obtain a liter of the mixture consisting of the liquid for checking injection equipment called calibration fluid for diesel injection equipment, the desired concentration must be established, which will be achieved volumetrically.

In the case of using an average granulation of 7 µm for the volumetric concentration of 0.1 and 0.2 dm^3/liter, the results presented below are obtained.

In fig. 4 the injection time variation diagram is presented for one liter of abrasive fluid with a density of 985.01 kg/m^3, corresponding to a concentration of 0.1 liters of abrasive particles per liter.

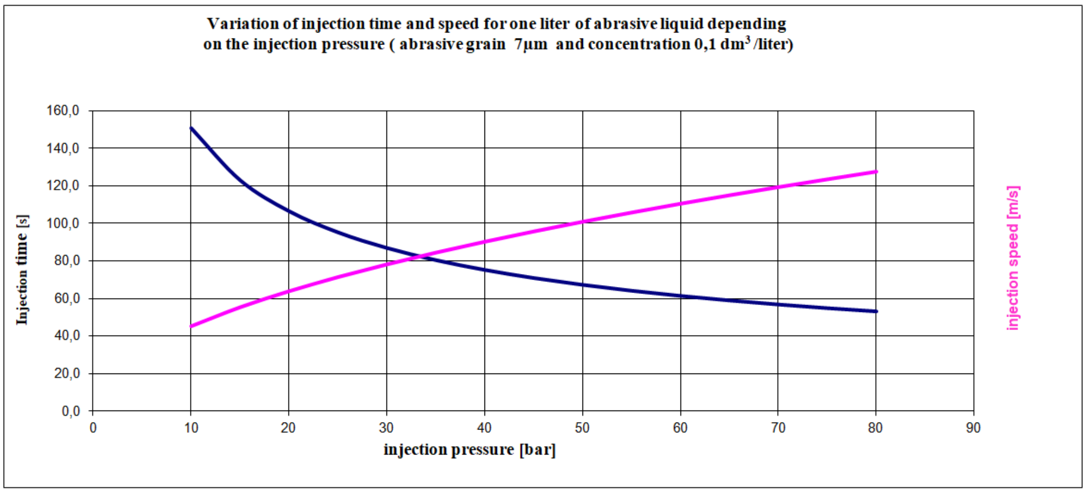

Fig. 4. The variation of injection time and speed for one liter of abrasive liquid with a concentration of 0.1 dm^3 abrasive powder per liter depending on the injection pressure

In fig. 5 the injection time variation for one liter of abrasive liquid with a concentration of 0.2 dm^3 abrasive powder per liter is plotted

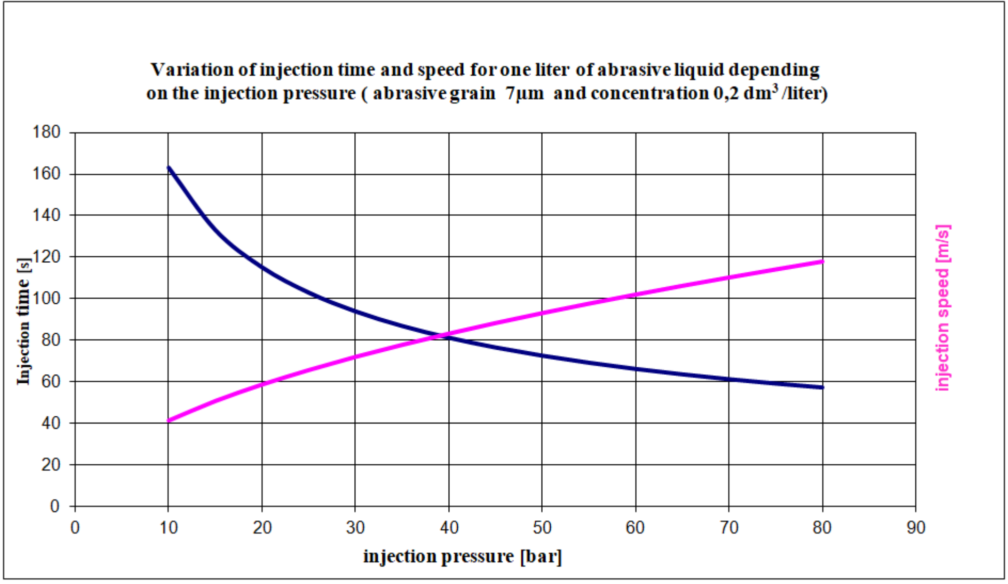

Fig. 5 Variation of injection time and speed for one liter of abrasive liquid with a concentration of 0.2 dm^3 abrasive powder per liter

In conclusion, the concentration must be selected that provides higher speeds, or statistically more abrasive particles for abrasive flow processing of the sharp edges of the injector nozzle hole, depending on the concentrations.

In fig. 6 compares the injection times and speeds for two concentrations of the abrasive fluid.

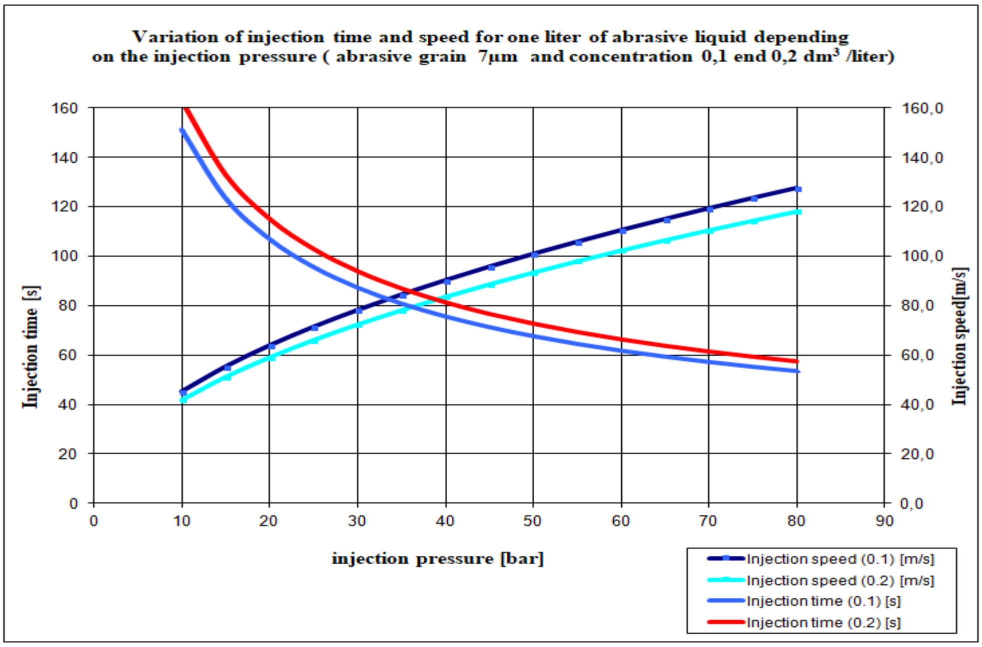

Figure 6. Variation of injection time and speed for one liter of abrasive fluid with a concentration of 0.1 and 0.2 dm^3 abrasive powder per liter

In the case of using an average granulation of 5 µm for the volumetric concentration of 0.1 and 0.2 dm^3/liter, the results presented below are obtained.

Fig. 7 shows the injection time variation diagram for one liter of abrasive liquid with a density of 985.01 kg/m^3, corresponding to a concentration of 0.1 liters of abrasive particles per liter.

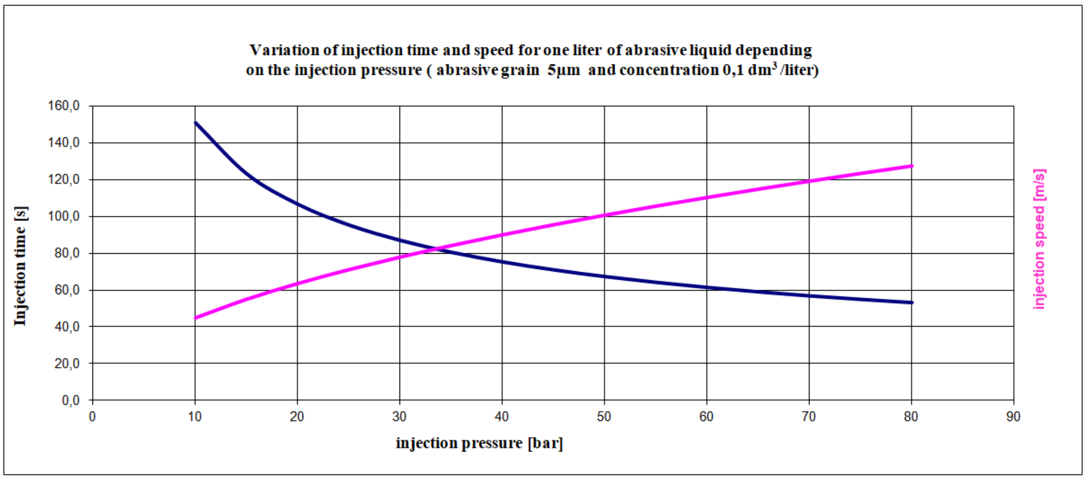

Fig. 7. Variation of injection time and speed for one liter of abrasive liquid with a concentration of 0.1 dm^3 abrasive powder per liter

In fig. 8 the injection time variation diagram for one liter of abrasive liquid with a density of 985.01 kg/m^3 is presented, corresponding to a concentration of 0.2 liters of abrasive particles per liter.

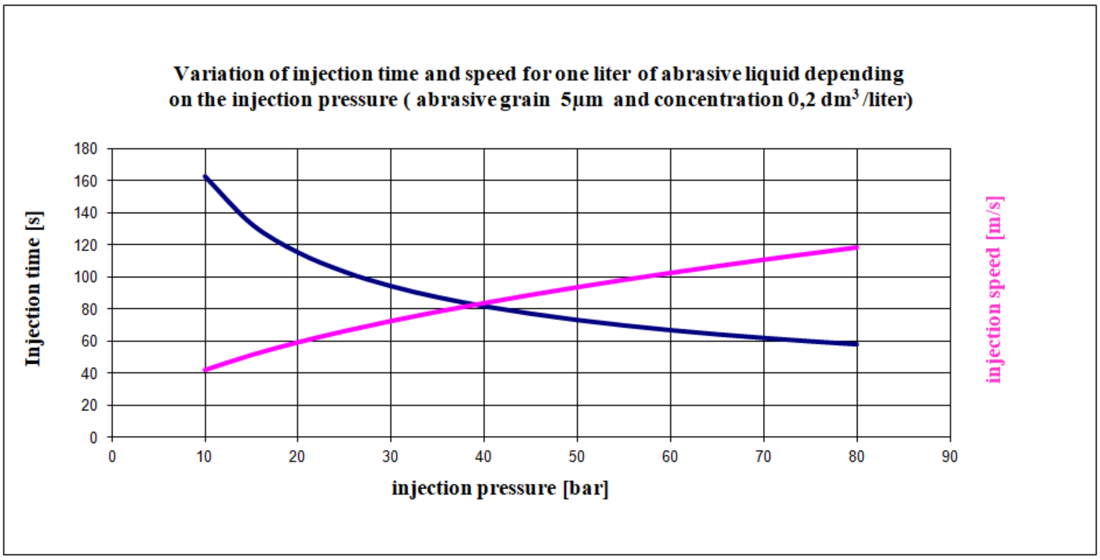

Fig. 8. Variation of injection time and speed for one liter of abrasive liquid with a concentration of 0.2 dm^3 abrasive powder per liter

In fig. 9 compares the fluid injection times and speeds through the fuel nozzle hole.

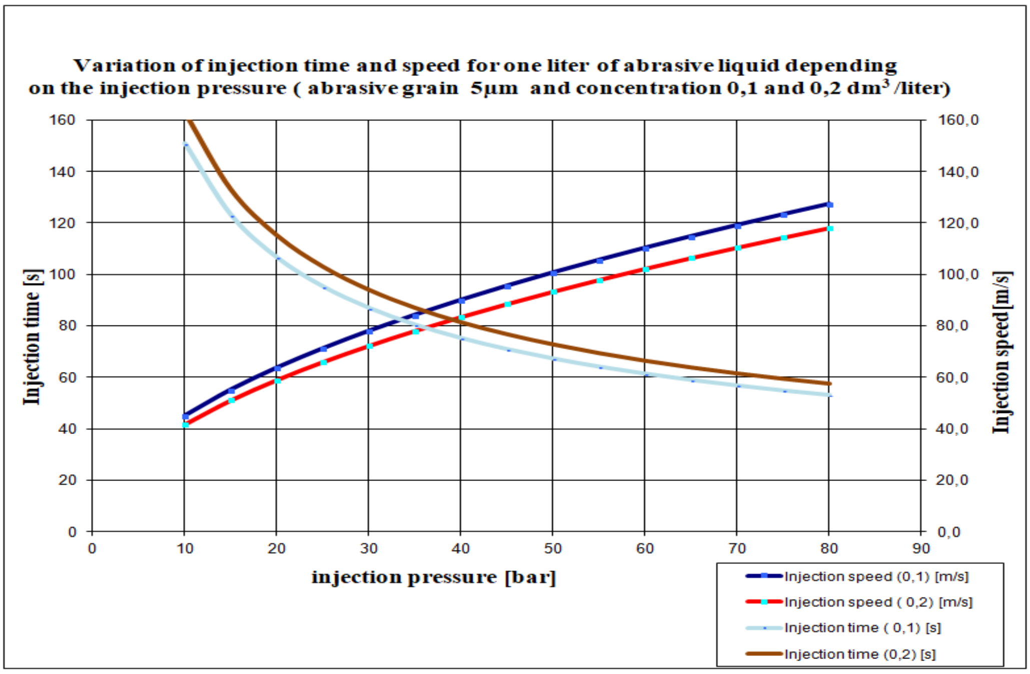

Fig. 9. Variation of injection time and speed for a liter of abrasive liquid with a concentration of 0.1 and 0.2 dm^3 abrasive powder per liter (granulation of abrasive particles of 5 µm)

Following the experimental analysis of the variation of injection times and speeds for one liter of abrasive fluid for abrasive particles with a grain size of 5 and 7 µm and a concentration of 0.1 dm^3/liter, the results presented in figure 10 are obtained.

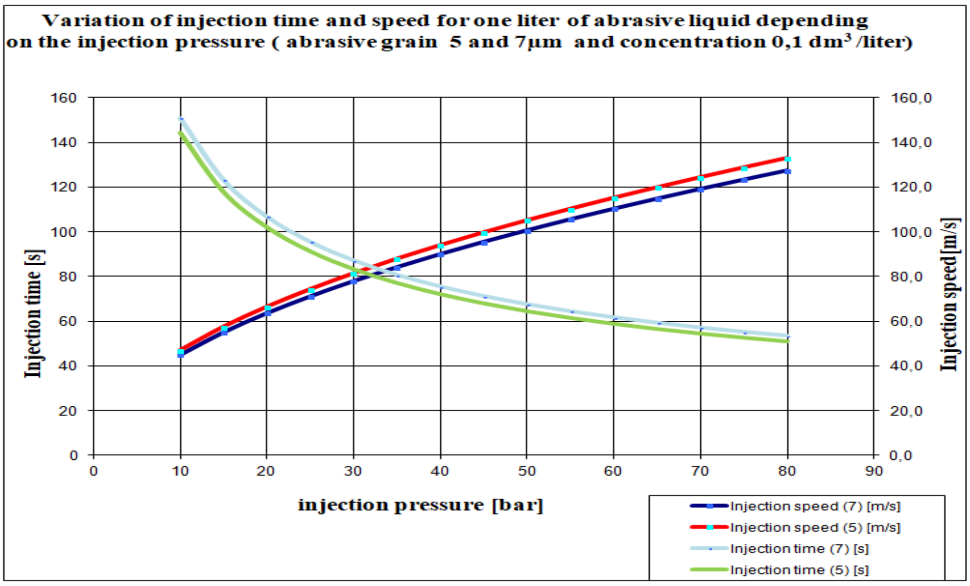

Figure 10. The variation of injection times and speeds for one liter of abrasive fluid for abrasive particles with a grain size of 5 and 7 µm and a concentration of 0.1 dm^3/liter

Following the analysis of the fluid passing through the fuel nozzle hole using the empirical relations (1) for the sweep length (the volume of the working flow on the cross section of the fuel nozzle hole) as well as for the internal bevel radius of the injection nozzle hole [11], the graph of their variation according to the pressure variation is obtained (figure 11).

$$L_s = \frac{V_{AFM}}{N_n \cdot A_n} \qquad (1\ )$$

$$Rc=1{,}508 \text{ X } 10^{-5}\ Ls^{1{,}34}$$

where V_{AFM} is the fluid volume, Nn-the number of fuel nozzle holes, and An-the cross-sectional area of the nozzle hole, and Rc is the internal bevel radius of the fuel nozzle hole.

Table Variation of Ls and Rc parameters according to fluid injection pressure

Pinj [bar]	Injection speed (0.1) [m/s]	Ls(m)	Injection time (0.1) [s]	Raza teşirii Rc
80	127,44995	0,006729357	53,4	1,94031E-06
75	123,40288	0,006515672	55,1	1,91481E-06
70	119,21851	0,006294737	57,1	1,88791E-06
65	114,88183	0,006065761	59,2	1,85945E-06
60	110,37489	0,005827794	61,6	1,82919E-06
55	105,67591	0,005579688	64,4	1,79685E-06
50	100,75803	0,005320024	67,5	1,76208E-06
45	95,587461	0,005047018	71,2	1,72443E-06
40	90,120723	0,004758374	75,5	1,68329E-06
35	84,300217	0,004451051	80,7	1,63784E-06
30	78,046835	0,004120873	87,1	1,58689E-06

25	71,246687	0,003761825	95,5	1,52867E-06
20	63,724974	0,003364679	106,7	1,46032E-06
15	55,187447	0,002913897	123,2	1,37669E-06
10	45,060361	0,002379187	150,9	1,26688E-06

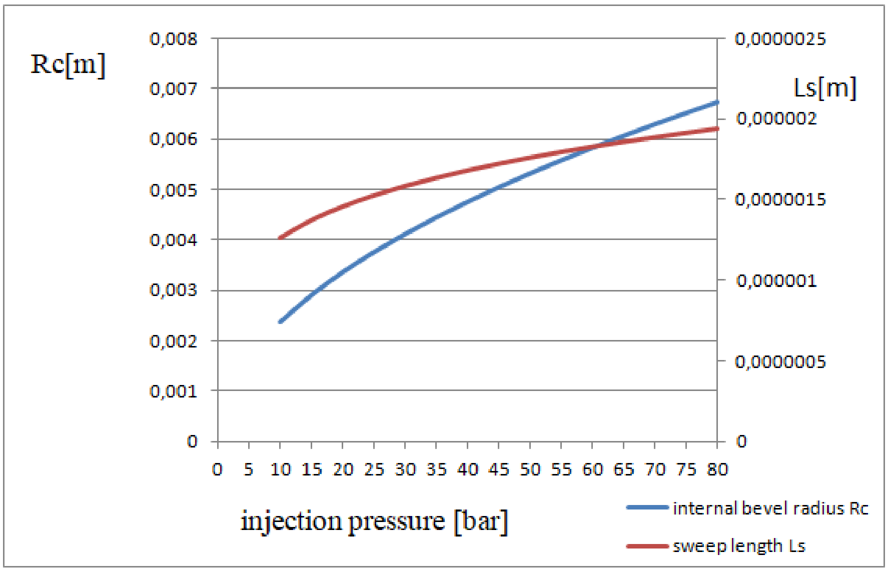

Figure 11. Variation diagram of the chamfering radius of the entry area in the injection nozzle hole as well as the sweep length Ls depending on the injection (extrusion) pressure of the fluid

3. Conclusions

Analyzing the variation diagrams presented above, conclusions can be drawn regarding the influence of abrasive flow processing parameters at different flow speeds of the abrasive fluid, providing an image regarding the variation of pressure, deformation speed and speed magnitude.

Following the analysis of the diagrams, the following conclusions can be found:

- the fluid injection speed increases with the increase in the extrusion pressure (injecting the fluid through the fuel nozzle hole), determining the improvement of the quality of the polished surface.
- with the increase in the percentage of abrasive particles in the working fluid, a decrease in the flow rate of the abrasive working fluid is obtained and therefore an increase in the erosion effect (by rooting the concentration level of the erosive fluid, the erosion intensity increases, resulting in a decrease in the quality of the polished surface)
- the increase in the size of the abrasive microparticles in the suspension of the working fluid causes a reduction in its flow speed through the fuel nozzle hole, resulting in an increase in the erosion effect on the surface of the flow hole in the injector nozzle and therefore a worsening of the flow through the fuel nozzle, increasing the speed of deformation, as well as increasing the duration of the fluid flow and implicitly a decrease in the quality of the surface;
-increasing the fluid injection pressure through the nozzle hole causes a decrease in the duration of the abrasive flux treatment process, but also an increase in the quality of the polished surface;

- the concentration of the abrasive is more significant than the flow rate of the medium.
- the increase in extrusion pressure causes a rounding of the inner area of the injection nozzle hole, thereby reducing cavitation and decreasing the concentration of particles at the entrance edge of the fuel nozzle channel.

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