

RESEARCH CONCERNING THE MECHANICAL PULVERIZATION CAPACITY OF PURE VEGETABLE OILS USED FOR ENERGETIC PURPOSES

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The study presents an analysis over the pulverization capacity of crude vegetable oils in energetic installations. The pumped mechanical pulverization has been taken into consideration. Judging by the physical- energetic characteristics of crude vegetable oils, the gauge of pulverization and angle of the jet's opening have been calculated. The analytic data has been verified on an experimental installation. The research's findings outline the possibility of the crude vegetable oils' usage in installations designed for fossil liquids.

Keywords: vegetable oils, mechanical pulverization, energetic purposes.

1. Introduction

The pure, crude vegetable oil or liquid fuel slightly additive by vegetable oil has a sliminess increased by approximately $20 \div 40$ % as opposed to the pure fossil one. The experimental research's role is to confirm the possibility of obtaining an adequate pulverization in classical energetic installations. The tests were carried out in the absence of heat.

A drop of liquid's breakage into finer particles is produced by the modification in the balance of forces which act upon it, according to Laplace's Law. By increasing the internal pressure p_i , the breakage of drops of d in diameter is produced, [1, 2]:

$$p_i = p_s + p_a = ct \quad (1)$$

Where: p_i is internal pressure of the liquid; p_s is pressure caused by superficial tension; p_a is pressure of the surrounding environment.

For a spherical surface of radius $r = d/2$ the $p_s = 2\sigma/r$, where σ represents the superficial tension of the liquid.

From the perspective of the principal of functioning, the injectors used in energetics can be classified in, [3, 4]:

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- Mechanical - the fuel's pulverization is produced on the basis of the under-pressure jet's kinetic energy, by its transition through a small orifice called nozzle/cap;
- Pneumatic (with steam or air) - the fuel's pulverization is produced on the basis of an auxiliary fluid's kinetic energy;
- Pneumatic-Mechanical, which are a combination of the two types presented above;
- With ultrasounds, which use the sonic waves' energy for the fluid's spraying.

The liquid's pulverization represents one of the initial stages of the burning process. Before burning, the liquid fuel passes into the gaseous state completely or partially, based on its chemical characteristics and the conditions in which the different phases of the burning process take place. The pulverization of the liquid's purpose is to increase the specific area of the liquid's weight inserted into the burning chamber under the form of a jet of drops. The jet's specific area increases with the decrease in diameter of the drops and implicitly increases the liquid's evaporation speed.

The theoretical and experimental research have shown that: the sliminess, density and superficial tension are physical properties of the liquid which influence the refinement of the pulverization (the medium diameter, the maximum diameter, the degree of dispersal).

2. The influence of sliminess

Along with the increase in sliminess, the valve's diameter (at the pulverization with a simple nozzle) or the thickness of the layer (at the pulverization with vorticity chambers), increases with the augmentation of the section of the nozzle's filling coefficient. After exiting the pulverized, the tub/valve or the layer breaks into ligaments which form drops. The drops then continue to break into even smaller droplets.

These formation and breakage processes of drops are influenced by the liquid's sliminess. The mechanical pulverization, the Sauter mean diameter, can be calculated based on the liquid's sliminess with the formula, [4, 5]:

$$d_s = A \left(\frac{\eta_l}{\rho_l} \right)^{0,215} \quad (2)$$

Where: A measurement dependent on the pulverizer's geometrical characteristic; η_l is the liquid's dynamical sliminess and ρ_l is the liquid's density

3. The influence of superficial tension(σ)

The superficial tension is a physical parameter which decelerates the

pulverization process. The increase in superficial tension leads to the attenuation of the nozzle or liquid layer after its exit from the pulverizer and implicitly at the formation of some drops with an increased diameter.

The superficial tension also decelerates the process of the drops' breakage (secondary pulverization).

The experimental results have shown that the superficial tension's influence on the drops' medium/mean diameter is dependent on the type of pulverizers, [5, 6].

For simple mechanical pulverizers::

$$d_m = f(\sigma^{0,2}) \quad (3)$$

For pulverizes with vorticity chambers::

$$d_m = f(\sigma^{0,1}) \quad (4)$$

The superficial tension has a direct influence on the breakage of liquid drops resulted from the primary pulverization. The critical, relative speed between the droplet and the environment $w_{r\ cr}$, at which the drop breaks, is given by the following relation, [7]:

$$w_{r\ cr} = c_1 \left(\frac{\sigma}{d} \right)^{0,5} \quad (5)$$

Where c_1 is a constant measurement.

4. The influence the liquid's density (ρ_l)

The turbulence inside the nozzle or the liquid cloth is one of the factors which cause their breakage and transformation into drops. The turbulence creates dynamic forces proportional with the liquid's density. The interior turbulence is dependent on the type of pulverizer as shown below:

For simple mechanical pulverizers, [4]:

$$d_m = f(\rho_l^{-0,074}) \quad (6)$$

For pulverizers with vorticity chambers, [4, 5]:

$$d_m = f(\rho_l^{(0,1-0,08)}) \quad (7)$$

Over the maximum diameter, the density's influence is given by the following relation, [6]:

$$d_{\max} = f(\rho_l^{-0,67}) \quad (8)$$

The proportion between the superficial tension's force (σ_l) and the inertia of the drop represents the main criteria for the pulverization (π_1). The inertia

force is characterized by the module $\rho_l w_l^2 d_{\max}$, in which ρ_l is the density of the liquid, w_l is the liquid's speed and d_{\max} the drop's diameter, [4]

$$\pi_1 = \frac{\sigma_l}{\rho_l w_l d_{\max}} \quad (9)$$

The connection between the liquid's sliminess $\eta_l \eta_l$ is carried out through the π_2 , criterion which considers internal friction through:

$$\pi_2 = \frac{\eta_l^2}{\sigma_l \rho_l d_{\max}} \quad (10)$$

The third criterion considers the environment's influence in which the pulverization takes place (air). If the air's density is noted ρ_a , the third criterion (called the density criterion) will become:

$$\pi_3 = \frac{\rho_a}{\rho_l} \quad (11)$$

The function characterizing pulverization is, [7]:

$$F(\pi_1, \pi_2, \pi_3) = 0 \quad \text{or} \quad \pi_1^m \cdot \pi_2^n \cdot \pi_3^p = \text{const.} \quad (12)$$

The complex function which comprises the process of pulverization's phenomenology is characterized by the equation:

$$\pi_1 (l + a_1 \pi_2)^{\frac{1}{12}} (l - a_2 \pi_3) = k \quad (13)$$

Where: $k = 4,8 \cdot 10^{-5}$; $a_1 = 10^6$; $a_2 = 0,5$.

For the injectors with mechanical pulverization (with a pump) it results:

$$d_{\max} = \frac{3,72 r_l^{0,56} \left(\frac{\eta_l 10^6}{2 \sigma_l \rho_l} \right)^{0,11}}{\left(\frac{\sqrt{1 - \varphi} \rho 10^4}{\sigma_l} \right)^{0,33}} \quad (14)$$

Where: d_{\max} is the debit coefficient (the filling of the exiting section) which depends on the pulverizer's structure, and over the pulverization pressure in the bar.

5. The characteristics of mechanical pulverization (with a pump)

For the refinement of pulverization's characterization, the notion of medium diameter of drops is used:

By the physical model, the following medium diameters can be defined:

- Sauter mean/medium diameter, defined as the particles' diameter from a homogeneous cloud which has the same area and number of particles as those of the studied cloud, [4]:

$$d_s = \frac{\sum_{i=1}^k d_i^3 n_i}{\sum_{i=1}^k d_i^3 m_i} \quad (15)$$

- Vitman mean/medium diameter, which represents the particles' diameter from a homogeneous cloud which has the same weight and number of particles as those of the studied cloud, [4]:

$$d_v = \frac{\sum_{i=1}^k d_i^3 g_i}{\sum_{i=1}^k d_i} \quad (16)$$

The experimental research/studies applied to the mechanical burner with vorticity chambers for the pulverization's pressure ranging from 10÷10.000 bars, the Vitman mean/medium diameter is calculated through the following relation, [8]:

$$d_v = d_0 \cdot C \cdot A \cdot \text{Re}^p \cdot \pi^k \quad (17)$$

Where: d_0 is the nozzle's diameter, C is an experimental constant, and A represents the injector's geometrical characteristic, p is the coefficient with the value, 0,7, k is the coefficient with the value 0,1, the constant $C=47,8$, and

$$A = \frac{(D_k - d_l)d_0}{n \cdot d_l^2} \quad (18)$$

Where: D_k is the vorticity chamber's diameter; d_l is the tangent pipes' diameter, and n is the number of tangent conduits.

The angle of the jet of pulverized particles' expanding θ can be calculated through the relations:

For liquids with reduced sliminess, [7]:

$$\frac{\text{tg } \theta}{\text{tg } \theta_0} = 3,05 \cdot 10^{-2} \left(\frac{D_k}{d_0} \right)^{-0,4} \pi^{-0,33} \quad (19)$$

For more viscous fluids ($\pi \geq 3 \cdot 10^{-4}$)

$$\frac{tg\theta}{tg\theta_0} = k\pi^{-0,33} \cdot Re \quad (20)$$

Where: $tg\theta_0 = \frac{2,83(l-\tau)}{\tau^3(1+\sqrt{1-\tau})}$; $\tau = 1 - \frac{d_0^2}{d_a^2}$; d_a the abrasion's diameter.

If the regime of operating is stationary, the dimension of the pulverization's angle tends towards the θ_0 value.

The particles' repartition in a jet respects a Gauss function of the second kind, the Rosin type. The weight percentage of particles which have a larger diameter compared to the reference diameter d is given by the law $R = 100 \exp(-d/d_m)^m$. The mean/medium diameter has been noted with d_m .

The curb's equation, which statically characterizes the ensemble, has the variation domain for $d \in (0, \infty)$. For the static processing of experimental data, the marginal dimension varies according to the probability's size, which represents 0,27 %. If the conditions of the curb's usage, at the particle's maximum and minimum diameter, are in concordance, then $R = 0,27 \div 99,73\%$. The coefficient of apportionment does not equal 3,28.

By applying these values it results, the maximum diameter of the particle will be:

$$d_{\max} = d_v \sqrt{5.924} \quad (21)$$

And the minimum diameter of the drop will be given by the relation:

$$d_{\min} = d_v \sqrt[3]{0.002761} \quad (22)$$

The variation interval for the drop's diameter will be given by the relation, [9]:

$$\frac{d_{\max}}{d_{\min}} = \sqrt[3]{2142} \quad (23)$$

6. Research concerning the pulverization capacity of vegetable oils

In the calculation relations the kinematical sliminess appears as the main characteristic. As resulted from the determinations which were made by ICEMENERG, Table nr.1 presents the kinematical sliminess' variation with the preheating temperature for more categories of crude vegetable oils.

In comparison with the light fossil fuels, the sliminess for mechanical pulverization must be between $(7 - 20) \cdot 10^{-6} \text{ m}^2/\text{s}$, [10].

To emphasize the pulverization's performance, the relation for the mean/medium diameter's calculation, according to Vitman, has been processed in

order to render evident the w_l is speed through the nozzle of pulverization d_0 . The connection between two measurements is represented through the criterion Reynolds $\left(R_e = \frac{w_l \cdot d_0}{\nu_l} \right)$.

Tabelul 1

Kinematic viscosity ν_c $[m^2/s]$

Temperature °C	Sort ulei		
	Corn	Soy	sunflower
15	91,8	79	86
20	72	63	69
30	45	42,5	43
40	30	30,5	32
50	21	22	24
60	15	16,8	18
70	12,2	13	14
80	6,7	10,5	11,2
90	5,5	8,8	10,3
100	4,6	7,3	7,6

By replacing the do value with the relation , a calculation relation of the medium/mean diameter for the particles of liquid which allow a direct connection with the burner's debit B, in kg/s, can be obtained,

$$B = \rho_l \frac{\pi w_l \cdot do^2}{4}, \text{ kg/s} \quad (24)$$

The liquid fuel's speed at its flow through the bean of pulverization is recommended in the 50-150 m/s range.

By the flowing speed of the liquid trough the injector w_l 's nozzle, the calculation of the medium/mean diameter according to Vitman will be transforming as shown below, [4, 10]:

$$d_v = \frac{\nu_c \cdot R_l^{0,3}}{w_l} C \cdot A \cdot \pi^{-1}, \text{ m} \quad (25)$$

Where: do is introduced in μm .

This relation has been applied to corn, soy and sunflower vegetable oil, at preheating temperatures up to 70 degrees Celsius, when the value of dynamic

sliminess is under $13 \cdot 10^{-6} \text{ m}^2/\text{s}$. This temperature is obtained through electrical preheating at burner destined for the burning of light liquid fuels (CLU), [11, 12]. The injector for whom the mechanical applications have been realized has the following consecutive data:

- The vorticity chamber's diameter, $D_k = 15 \text{ mm}$
- The tangent conduits' diameter, $d_t = 1 \text{ mm}$
- The number of tangent pipes, $n = 4$
- The bean of pulverization's diameter, $d_0 = 1 \text{ mm}$

By applying the calculation (18) for the constant A , the following figure resulted: $A = \frac{(15-1) \cdot 1}{4 \cdot 1^2} = 3,5$.

Figure 1 presents the variation in Vitman mean/medium diameter for sunflower oil with the variation in sliminess at the preheating temperature ranging from 30 to 70 degrees Celsius, the nozzle of liquid's speed in the nozzle of pulverization varying between 50 and 150 m/s.

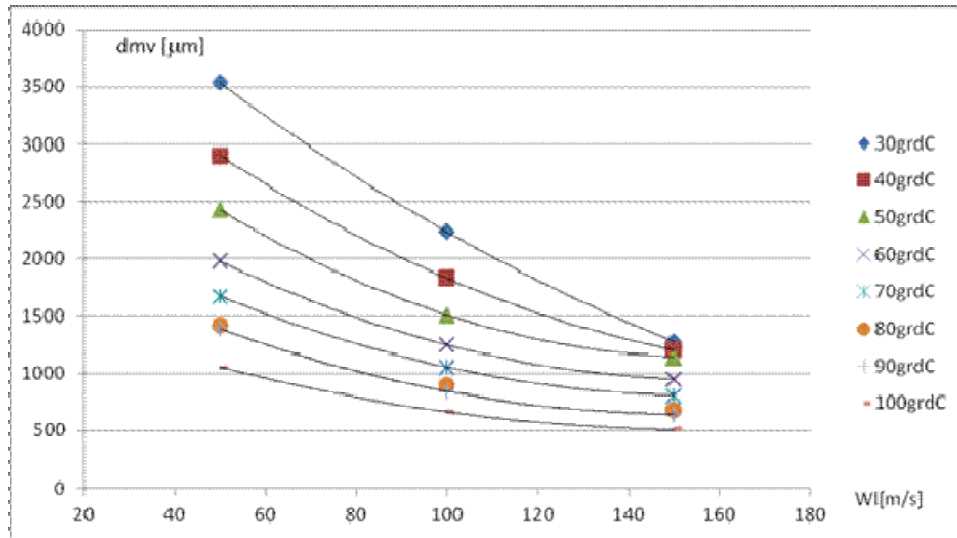


Fig. 1. The medium diameter of the sunflower oil particles, pulverized by an injector with a vorticity chamber and nozzle diameter $d_0=1\text{mm}$, pressure of 40 bars.

Figure 2 presents the variation in Vitman mean diameter for corn oil at the preheating temperature ranging from 30 to 70 degrees Celsius, the nozzle's speed of pulverization varying between 50 and 150 m/s.

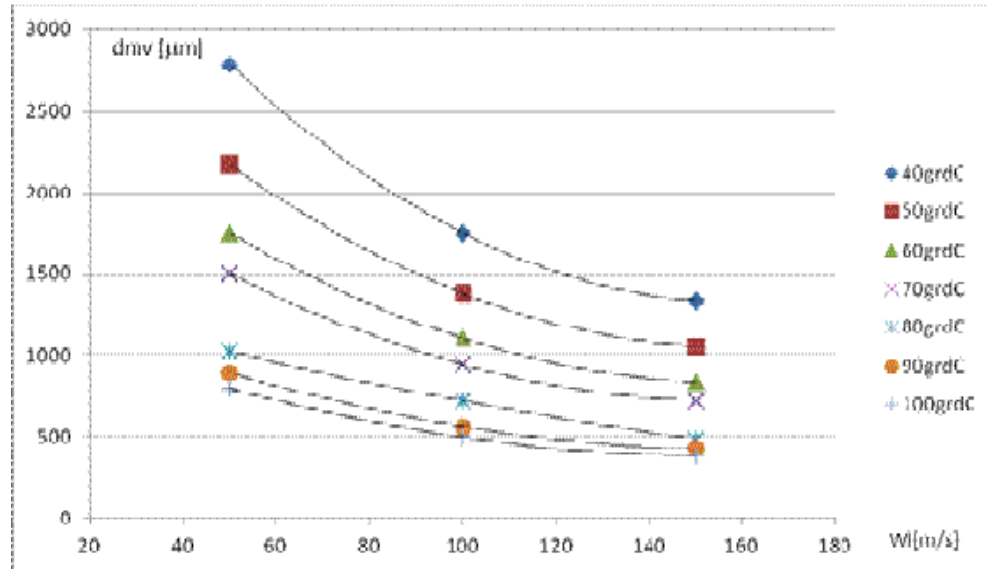


Fig. 2. The medium diameter of the corn oil particles, pulverized by an injector with a vorticity chamber and nozzle diameter $d_0=1\text{mm}$, pressure of 40 bars.

7. Experimental research concerning the pulverization of vegetable oils

The experimental research has been made on a stand from the Department of Thermo-Technology, Engines, Thermal and Frigorific Equipments of the Polytechnic University of Bucharest.

The stand presented in Figure 3, allows the pulverization of liquids in the technology of the pump injectors' usage, but also in that of auxiliary under-pressure liquid's usage.

For the experiments, the stand has been equipped with a 200 kg/h injector, presented in Figure 4, with vorticity chamber and return adjustment, pulverization pressure being adjusted for the 35-40 bars range.

The pulverization nozzle's diameter measured 1 mm and the return chamber's geometrical characteristic has the value $A=3,5$, similarly to the conditions of calculation.

For a more exact simulation of the actual conditions, the injector is surrounded by the burning draught, produced by the ventilator.



Fig. 3. The experimental stand for the study of pulverization



Fig. 4. The image of an injector attached to the conduit of vorticity air

The experiments have confirmed the measurement of the pulverization angle symbol and a uniform/unvarying repartition of particles in the transversal section of the jet, as shown in Figures 5 and 6. The image in Figure 6 is for a pulverization pressure of 40 bars, and that from Figure 6 for a pressure of 35 bars.

Figure 6 shows the pressure for realizing a certain density for briquettes in a strong connection to the initial density of the straw cutting.



Fig. 5. The aspect of the jet being pulverized at a 40 bars pressure



Fig. 6. The aspect of the jet being pulverized at a 35 bars pressure

8. Conclusions

The calculation model emphasized the possibility of the sunflower oil's usage only after a heating of minimum 70 degrees Celsius, and preferably at a speed in the pulverization nozzle exceeding 100 m/s, when the medium diameter is below 100 Symbol.

The corn oil can be more easily calculated than the sunflower one, as it has a lower sliminess. The same range of applicability as that of sunflower oil is emphasized, the refinement of pulverization being more efficient, by 12 %.

According to the medium diameter, the maximum diameter for the pulverized jet has been calculated, resulting:

- *Sunflower oil*

For the most unrefined medium diameter accepted:

$$\text{Maximum diameter: } d_{\max} = 1055 \cdot \sqrt[3]{\frac{2,83}{5,924}} = 1055 \cdot 1,809 = 1300 \mu\text{m}$$

$$\text{Minimum diameter: } d_{\min} = 1055 \cdot \sqrt[3]{\frac{2,83}{0,002761}} = 1055 \cdot 0,14 = 147,7 \mu\text{m}$$

- *Corn oil*

For the finest pulverized diameter:

$$\text{Maximum diameter: } d_{\max} = 507 \cdot \sqrt[3]{\frac{2,83}{5,924}} = 507 \cdot 1,809 = 916 \mu\text{m}$$

$$\text{Minimum diameter: } d_{\min} = 507 \cdot \sqrt[3]{\frac{2,83}{0,002761}} = 507 \cdot 0,14 = 70,98 \mu\text{m}$$

The opening angle of the pulverized jet is determined by the relation (16); where the relation $r = 1$, resulting for a stationary regime of pulverization:

$$t_g \theta_0 = \frac{2,83}{2} = 1,41 \quad \Rightarrow \quad \theta_0 = 54,65^\circ \quad (26)$$

Starting with the physical and chemical characteristics of vegetable oils at certain temperatures, the characteristics of pulverization for crude corn or sunflower vegetable oil have been presented. Due to its lower sliminess, corn oil can be pulverized in the same conditions with about 12 % more refinement than the sunflower one.

The mathematical model utilized allowed the delimitation of the optimum conditions of pulverization, which would mean a heating of 70 degrees Celsius and a speed in the nozzles at the exit of the injectors with pump mechanical pulverization of over 100 m/s.

The pulverization research made on a stand from the Polytechnic University of Bucharest has validated the data calculated.

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