MATHEMATICAL MODELS FOR EXPRESSING THE OIL EXTRACTION AT SCREW PRESSES

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This paper presents the results obtained by pressing sunflower seeds using a constant diameter screw press, with circular holes for oil drainage and a single nozzle for cake outlet. The results show the dependence between the oil yield and the nozzle diameter, the variation of the oil percentage expressed along the pressing chamber and the variation of the sediment percentage of the expressed oil with the nozzle diameter. The experimental results obtained at the pressing were subjected to regression analysis using Microcal Origin version 7.0 program. It was observed which regression equation has the best correlation with the experimental results.

Keywords: screw press, oilseeds, mathematical model, regression analysis

1. Introduction

The raw materials for vegetable oils industry are the oilseeds which represent an important component of modern agriculture. From oilseeds, highly nutritious human food and oil crops can be easily obtained, and these products represent some of the most important commerce commodity. Vegetable oils are a major source of vitamins, calories and essential fatty acids for human consumption, obtained at a relatively low price, [1].

The process of oil extraction from oilseeds may be carried out mechanically by pressing, or chemically using solvent extraction methods. By analyzing the two methods, we can say that the press is a simpler method than solvent extraction, but it is less effective regarding the amount of residual oil left in the cake, [2].

Screw pressing, also called oil expression process, is the most common method for extracting vegetable oil from oilseeds in small and medium-sized plants, [3]. Nowadays, the largest amount of vegetable oil used in food industry is produced in large capacity industrial plants using solvent extraction, while the screw presses are mainly used for preliminary pressing of the seeds with a high

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content of oil. Screw presses are also extensively used to achieve virgin vegetable oil in developing countries and for obtaining vegetable oils used as fuel, [4].

Because the chemical method of oil extraction uses a hexane as solvent, the interest in replacing hexane with another solvent has increased. One of the reasons is that hexane has a high risk of flammability and toxicological harm for the environment and human health. Several alternative solvents have been reported by a few researchers in the scientific literature, [5].

Numerous attempts have been made to improve the efficiency of oil extraction through pressing, [6]. In general, three types of intervention have been studied: optimization of the operating parameters of the process, improvement of the geometric configuration of the press and pre-treatment of the seeds. However, many of these studies are the result of criteria based on experience and intuition of manufacturers and operators rather than on a rigorous theoretical analysis of the physical principles involved in the process, [7,8].

Although screw presses have been used for decades in the vegetable oil industry, no satisfactory mathematical models are available to describe the pressing process, as in the case of solid-liquid separation processes, [4]. Over the last 15 years many studies based on the development of simulation models of the extraction process for different types of seeds have been published, [2,6,9,10,11]. If hydraulic oil expression using discontinuous presses can be satisfactory simulated using Shirato type models - based on the soil consolidation theory, not the same thing happens when oil is expressed using screw presses, [12]. Vadke et al., [13], applied the Shirato model to a laboratory screw press and achieved relatively good results for the prediction of seed throughput and press cake residual oil, but only when the working conditions were very close to those of Shirato model. Willems et al., [14], have improved Vadke model and applied it to gas assisted mechanical expression (GAME), but the influence of temperature on the pressure and the residual oil was not satisfactorily predicted. Moreover, these models could not determine the presence of solid impurities in oil or energy requirements. A theoretical model based on cellular structures of oilseeds was developed by Lanoisellé et al., but has not been applied for the continuous oil expression, [4].

This paper aims to enrich the literature by providing experimental results obtained at the sunflower seeds pressing process using laboratory equipment, meaning a cylinder hole type screw oil press.

2. Material and methods

PU-50 oil press used in the experiments is a press from the laboratories of Faculty of Biotechnical Systems Engineering, which is manufactured by STIMEL Timisoara. It is a small capacity press, with constant diameter and pitch of the screw, which is used for oilseeds cold pressing and has two coaxial exhausts ends (each of them having a cylinder with holes and a screw inside). The length of the oil outlet and collection zone is approximately 40 mm and for the cake discharge one central nozzle is provided, for each exhaust end. The experiments were carried out using only one exhaust end.

The performances of this screw press (available when using sunflower seeds cleaned, with a minimum of 48% oil content and 6-8% moisture content) are shown in table 1:

Table 1

Performance of PU-50 oil press with two exhaust ends, [15]

Performance	PU-50
Productivity (l/h)	16-19
Throughput (kg/h)	38-42
Oil yield (%)	38-42
Feeding hopper capacity (dm^3)	approx. 37
Electrical motor power (kW)	3

The material used in experiments consisted of whole (undecorticated) sunflower seeds, from Procera PRO 229 variety, harvested in farms of Giurgiu County, Romania, with density of 410 kg/m^3 and moisture content of 4.9%. Before starting the experiments, the screw press was heated using heating electrical resistance of the press for 20-30 minutes, until the pressing chamber temperature reached 80-90ºC. When this temperature was reached, the resistances were disconnected and feeding of the press with sunflower seeds started.

Fig. 1. The collection of expressed oil in the compartmented tray and then in plastic bottles

The experiments were carried out in three stages, each stage using a different nozzle to the exhaust end of the press, which is equivalent to the variation of the pressure in the chamber. The nozzles used in the experiments had a diameter of 8, 10 and 12 mm.

The amount of seed that was subjected to pressing in all the three cases was 15 kg, but the feed rate was different due to the different diameters of the nozzles, the screw speed remaining unchanged in the experiments. The oil outlet zone has been provided with a collector tray which has four equal compartments, as shown in Figure 1, in order to determine the extraction degree along the separation chamber. After each experiment, the expressed and collected material from the oil outlet zone, as well as the amount of cake press, was weighed.

The liquid expressed material was left to decant for three days, and then manually separated into two components: oil and impurities. Neither impurities nor cake were further subject to a process of oil extraction using a solvent, so that the oil fraction separated after decantation was considered oil obtained by cold pressing (at room temperature). Therefore, the purpose of experimental determinations was only to estimate the expression degree along the pressing chamber and to estimate the oil yield.

3. Results and discussion

The values of the two fractions obtained at the decantation process, as well as the results obtained at the pressing process, are given in Table 2.

Table 2

Values of fractions obtained at pressing for the three exhaust nozzles, based on the weight of the seed sample (15 kg)

Nozzle diameter (mm)	Expressed material (oil+impurities) (kg)	Decanted oil		Impurities		Cake	
		(kg)	(%)	(kg)	(%)	(kg)	(%)
8	5.18	3.12	20.82	2.05	13.69	9.68	64.57
10	5.02	3.07	20.44	1.96	13.06	9.89	65.96
12	4.87	3.01	20.05	1.86	12.43	10.10	67.35

The amounts of oil obtained in the four compartments of the collection tray are shown in Table 3. In the same table, are also given, as percentages, the cumulatively quantities of expressed oil from the length of the separation zone.

Analyzing data from Table 3, it can be observed that in all three experimental conditions (nozzles of different diameters), the maximum percentage of oil obtained after decantation has not exceeded 20.8%, regardless of the nozzle diameter. However, the degree of expression increases dramatically with the decreasing of the nozzle diameter.

Table 3

Expressed oil quantities along the collection zone and the cumulatively oil percentages, for the three nozzles

	Expressed oil (kg)			Cumulatively percentage of expressed oil (%)		
Nozzle (mm) / Compartment	8	10	12	8	10	12
C1	2.79	2.82	2.84	20.82	20.44	20.05
C2	2.09	1.76	1.43	9.53	8.85	8.17
C3	0.28	0.34	0.4	1.15	1.78	2.41
C4	0.02	0.11	0.199	0.08	0.45	0.81

Given the complexity of the expression and separation oil process, for screw presses, as well as for hydraulic presses, a mathematical expression of the degree of oil extraction on the length of the zone with holes for oil drainage has been proposed. This was achieved by testing the variation of the experimental data by computer regression analysis using Microcal Origin vers. 7.0 program, with an exponential law, such as:

$$P_x = a \cdot e^{b \cdot x} \tag{1}$$

where: P_x (%) – represents the cumulatively oil percentage separated along the length x (mm) of the press separation zone; a, b – constants that depend on the working process parameters of the press and on the characteristics of the pressed material.

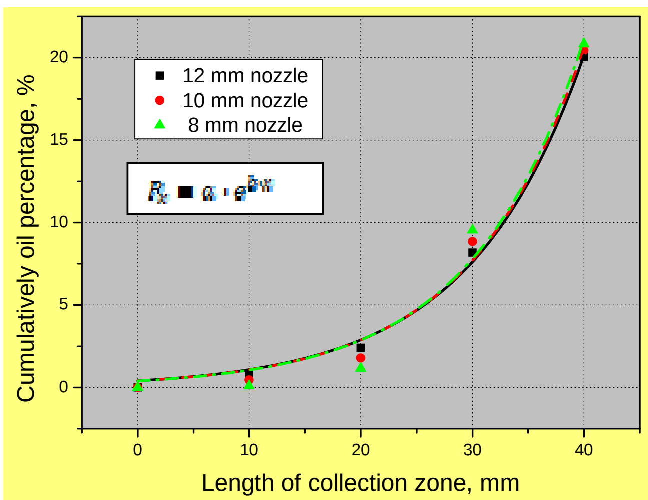

Fig.2. Variation of the cumulatively oil percentages along the collection zone, for the three nozzles, using the exponential distribution law

The analysis was carried out for each of the three sets of experimental data, that is, for each of the three types of nozzles for cake outlet.

Analyzing the graph from Figure 2, it can be noticed that the first zone of the oil collection and separation chamber, the percentage of oil extracted is relatively low, which means that the pressure on the material is relatively low, especially if we take into account that the screw press has constant diameter. In the second part of the collection zone, the percentage of extracted oil rapidly increases, reaching a maximum at its end, but not exceeding a value of 20.82% for any of the three considered cases.

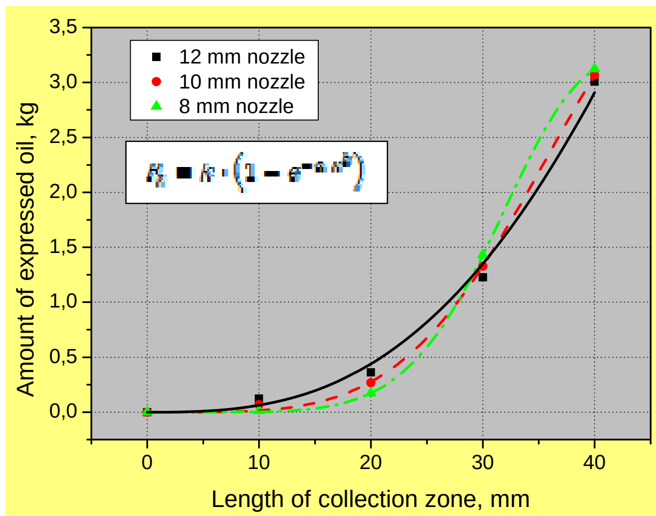

Fig.3. Variation of the cumulatively oil percentages along the collection zone, for the three nozzles, using the Rosin-Rammler distribution law

The same allure of the variation curves can be noticed in the graph of oil extracted (in kg) along the pressing chamber (see Figure 3), regardless of the nozzle diameter, in the figure being presented the variation curves represented by the Rosin-Rammler distribution law, also obtained by computer regression analysis:

$$P_x = k \cdot \left(1 - e^{-a \cdot x^b}\right) \tag{2}$$

where: P_x, a, b – have the same meaning as in equation (1); k – experimental coefficient which depends on the maximum percentage of separated oil on the x length of the separation zone.

The coefficients values of the relationship together with the correlation coefficient values obtained by regression analysis are shown in Table 4.

Table 4

The coefficients values of the (1) and (2) regression equations and of the R^2 correlation coefficient, for the three nozzles types

Nozzle diameter (mm)	Coefficients of the (1) and (2) regression equations							
	k		a		b		R^2	
	Ec. (1)	Ec. (2)	Ec. (1)	Ec. (2)	Ec. (1)	Ec. (2)	Ec. (1)	Ec. (2)
8	-	9.709	0.389	$1.593 \cdot 10^{-6}$	0.099	3.364	0.978	0.994
10	-	16.046	0.398	$1.622 \cdot 10^{-6}$	0.099	3.193	0.990	0.998
12	-	21.166	0.410	$1.537 \cdot 10^{-6}$	0.097	3.118	0.997	0.999

After decanting the material collected through the holes of the outlet zone in the four compartments of the tray, quantities of impurities decanted were reported to the total amount of expressed material (oil + impurities discharged through the holes) and the percentages obtained are shown in Table 5, for the three used nozzles, cumulatively on the discharge zone. Based on these values, the variation curves were plotted (Figure 4).

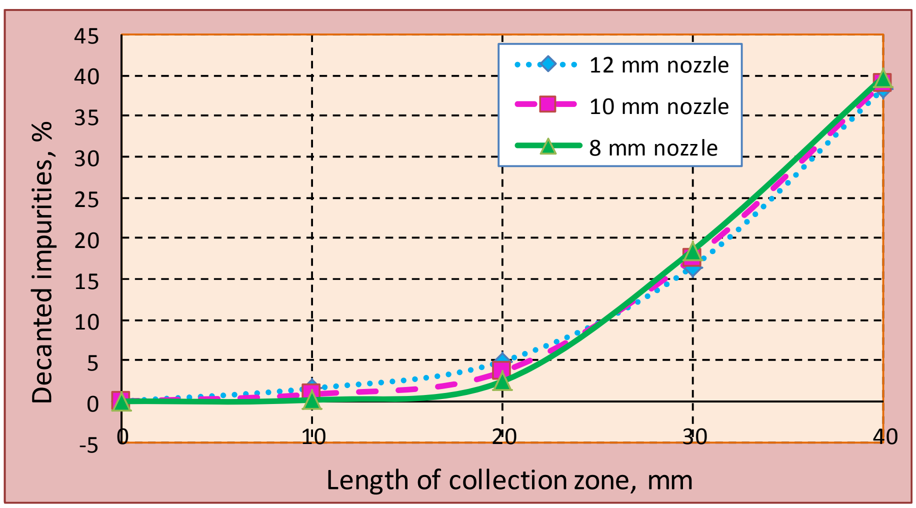

Fig.4. Variation of the decanted impurities percentage along the collecting zone, for the three nozzles

As mentioned above, the amounts of impurities expressed together with the oil through the separating zone holes increases from the feeding area of the press to the cake discharge area regardless of the nozzle type, but the increase is higher for the nozzles with smaller diameter at the cake discharge. Obviously, these impurities are very small, smaller than the holes from the oil outlet zone.

Table 5

Cumulatively percentages of the decanted impurities, based on the amount of expressed material, for the three nozzles, along the collection zone

Collection zone length (mm)	Decanted impurities percentage, %		
	12 mm nozzle	10 mm nozzle	8 mm nozzle
0	0.00	0.00	0.00
10	1.58	0.86	0.17
20	4.89	3.62	2.43
30	16.50	17.52	18.49
40	38.26	38.99	39.68

For theoretical description of the oil total separation curve along the oil separating and drainage zone, for the screw presses, many types of mathematical relationships have been used in the literature, including: exponential distribution function (eq. 1), Rosin-Rammler function with k = 100 (eq. 2), Gauss function (eq. 3), exponential function with exponent of I degree (eq. 4), logistic function with two parameters (eq. 5) and power function (eq. 6) expressed by the following equations:

$$P_x = 100 \cdot \left(1 - a \cdot e^{-b x^2}\right) \qquad \text{Gauss function} \qquad (3)$$

$$P_x = 100 \cdot \left[1 - e^{-a(x-b)}\right] \qquad \text{exponential function (with exponent of I degree)} \qquad (4)$$

$$P_x = 100 \cdot \frac{\exp\,(a + b \cdot x)}{1 + \exp\,(a + b \cdot x)} \qquad \text{logistic function} \qquad (5)$$

$$P_x = a \cdot x^b \qquad \text{power function} \qquad (6)$$

where P_x, a, b have the same meaning as in equation (1).

Table 6

Cumulatively percentages of oil expressed along the collection, for the three nozzles

Collecting zone length (mm)	Percentage of expressed oil (%)		
	12 mm nozzle	10 mm nozzle	8 mm nozzle
0	0.00	0.00	0.00
10	0.81	0.45	0.08
20	2.41	1.78	1.15
30	8.17	8.85	9.53
40	20.05	20.44	20.82

On the basis of the amount of oil (in percentage) cumulatively presented in Table 6, experimental points were plotted, separately for each of the three nozzles, representing the percentage of oil expressed along the separation and collection zone. Using these data, by computer regression analysis using Microcal Origin vers. 7.0 program, the separation curves were drawn off using the distribution law given by equations (1-6) above. The experimental points along with the regression curves are shown graphically in Figures 5, 6 and 7. Values of the regression equations coefficients and correlation coefficients R^2 are also shown in Table 6.

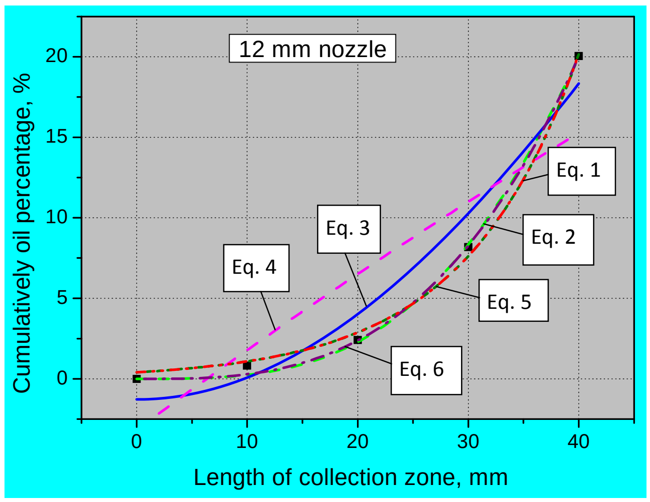

Fig. 5. Variation of the cumulatively oil percentages expressed along the collection zone, for the 12 mm nozzle, and the separation curves using (1)-(6) distribution laws

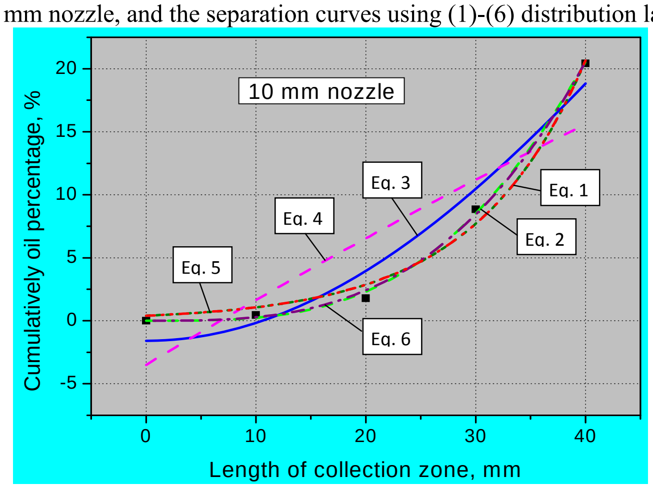

Fig. 6. Variation of the cumulatively oil percentages expressed along the collection zone, for the 10 mm nozzle, and the separation curves using (1)-(6) distribution laws

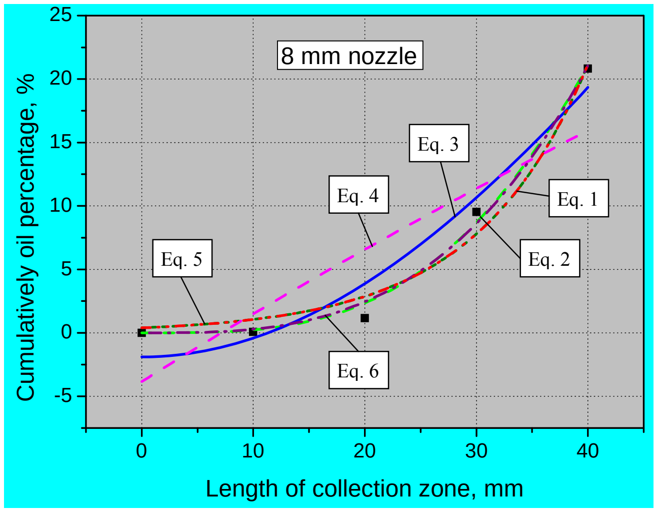

Fig.7. Variation of the cumulatively oil percentages expressed along the collection zone, for the 8 mm nozzle, and the separation curves using (1)-(6) distribution laws

Table 7

Coefficients values of the regression equations and of the R^2 correlation coefficient, for the cumulatively oil percentage along the pressing chamber, using different nozzle types

Equation type	12 mm nozzle			10 mm nozzle			8 mm nozzle		
	a	b	R^2	a	b	R^2	a	b	R^2
Eq. (1)	0.410	0.097	0.997	0.398	0.099	0.990	0.389	0.010	0.978
Eq. (2)	$1.29\cdot10^{-6}$	3.270	0.999	$1.201\cdot10^{-6}$	3.297	0.998	$1.149\cdot10^{-6}$	3.316	0.993
Eq. (3)	1.013	$1.3\cdot10^{-4}$	0.956	1.016	$1.4\cdot10^{-4}$	0.957	1.019	$1.5\cdot10^{-4}$	0.955
Eq. (4)	0.005	6.331	0.789	0.005	6.746	0.783	0.005	7.136	0.775
Eq. (5)	-5.507	0.097	0.997	-5.536	0.099	0.990	-5.560	0.010	0.978
Eq. (6)	$2.4\cdot10^{-4}$	3.070	0.999	$2.3\cdot10^{-4}$	3.090	0.998	$2.2\cdot10^{-4}$	3.106	0.991

Analyzing data from Table 7 and the separation curves shown in Figures 8, 9, 10, it is found that the best correlation of the distribution laws presented with the experimental points has the Rosin-Rammler distribution law, followed by power law ($R^2 \geq 0.993$ for Rosin-Rammler law or $R^2 \geq 0.991$ for power law).

High values of the R^2 correlation coefficients have also been obtained for logistic and exponential simple distribution laws, with values of the correlation coefficients $R^2 \geq 0.978$ for both equations. The weakest correlation is presented by the I degree exponential distribution law for which $R^2 \geq 0.789$. From the above, it is clear that the presented distribution laws can be successfully used to predict the expression process of oil for all oil presses with constant diameter of the screw, as well as for other oilseed crops, especially Rosin-Rammler and power distribution laws. It should be noted, however, that the coefficients values of the regression equations can significantly alter both structural and functional characteristics of the press and the physical properties of oilseeds. Also, for both the Rosin-Rammler distribution equations and the power equations, the first coefficient of these equations has an insignificant influence on the values of extracted oil percentage, showing very low values (smaller than $2 \cdot 10^{-4}$).

4. Conclusions

The oil extraction process at screw presses is governed by a couple of factors, some of them being quantifiable and some of them being less quantifiable, which demonstrates the complexity of the process and its mathematically expression.

At the presses with constant-diameter screw and pressing chamber equipped with circular holes for oil drainage and with a single nozzle for cake outlet, the percentage of expressed oil along the pressing chamber has mainly an exponential variation, regardless the material feeding rate or the nozzle diameter.

For PU-50 oil press (Stimel Timişoara), percentage of expressed oil by pressing sunflower seeds had values between 20.05 and 20.82%, using nozzles with ϕ12 mm, respectively ϕ8 mm diameter, for cake outlet. It has been found that the higher the nozzle diameter, the smaller the oil yield and vice versa. It results that a large amount of oil remains in the cake, or not expressed from the seeds, or between the cake particles, when the nozzle diameter is bigger.

In addition, together with the expressed oil amount, through the press holes small sediment particles were also discharged and their percentage was higher for the nozzle with smaller diameter, respectively 13.69% for 8 mm nozzle, compared to 12.43% for the 12 mm nozzle.

It is also observed, that the seed feed rate has changed when the nozzle diameter for cake outlet was changed, the two parameters being directly proportional.

The results of the work can be used by the specialists in the field to determine the most appropriate values of the operating parameters for the screw presses with a single nozzle (for cake outlet) in order to obtain the maximum expressed oil yield, not only for sunflower seeds, but also for other oilseeds types.

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