NECESSARY POWER FOR OIL PRESSES DRIVE

S.Şt. Biriş, M. Manea, N. Ungureanu, M. Tudosie, V. Vlăduț

***Abstract**: Mechanical continuous presses are the most commonly used machines for the pressing of oleaginous materials in oil industry. This paper contains a theoretical model regarding the power necessary to operate an oil press. The necessary components to power the press are: the power needed to transport the material along the pressing chamber, the power required to press the oleaginous material, the power needed to overcome the friction between the screw spire and the material, the power needed to push the material from the press through the exhaust cylinder head.*
***Key words:** Continuous mechanical press, Pressing, Power, Mathematical model, Oil industry.*

INTRODUCTION

Due to the advantages it presents (continuous operation, high working capacity, running without high shocks and vibrations, working pressures which can be easily adjusted, etc.) the mechanical continuous presses are mostly used in food industry, especially for pressing the grapes in wine industry and the oily material in oil industry.

The theoretical elements for a functional calculus, as well as those for the power necessary for operating the press are actually rather poor, being based especially on simple formulas containing some correction coefficients, whose value is empirically obtained from experiments. This is due to the complexity of the processes and phenomena taking place during the pressing process, such as: material transport, proper pressing, overcoming the frictions between the auger and the material, pushing the material through the slot at the end of the pressing chamber.

In figure 1 is presented a representative mechanical continuous press with variable auger diameter and pitch, used to press the oily material in oil industry, which can reach pressures up to 40 MPa in the pressing chamber.

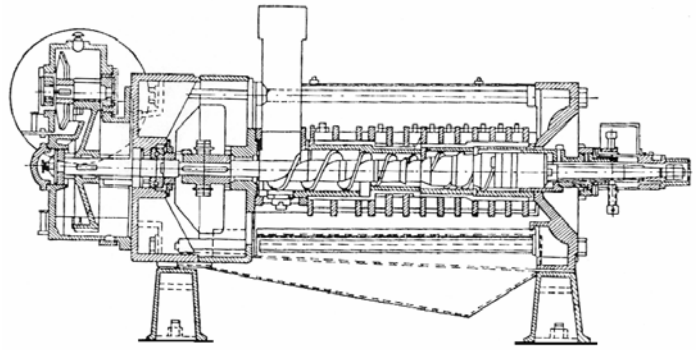


Fig. 1. Mechanical Continuous Press Used in Oil Industry

THEORETICAL ELEMENTS

Pressure ratio (representing the reduction of the material subdued to the pressing process) is calculated by the relation [1]:

$$\varepsilon = \frac{V_i - V_f}{V_i} \quad (1)$$

where: V_i –represents the initial volume of the material, [m^3] and V_f –the final volume, [m^3].

The value of the pressure ratio is directly proportional to the press working pressure, having a variation, as that one shown in figure 2.

Press volume flow rate can be evaluated by using the relation [2]:

$$Q_v = V_{te} \cdot (1-\varepsilon) \cdot n \cdot k \cdot 60 \quad [\text{m}^3/\text{h}] \quad (2)$$

where: V_{te} – the theoretical volume of material displaced by the auger spire during a complete rotation, in the exhaust area [m^3]; n – the auger rotational speed, [min^{-1}]; k – coefficient that takes into account the material flowing back through the spire extremities, as well as the incomplete feed with material, (k=0,2÷0,35).

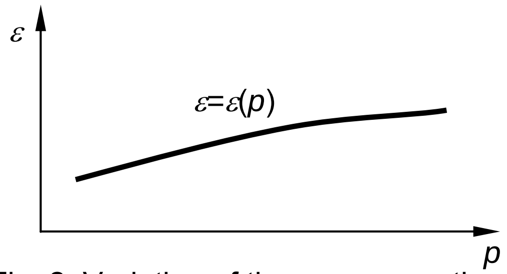


Fig. 2. Variation of the pressure ratio

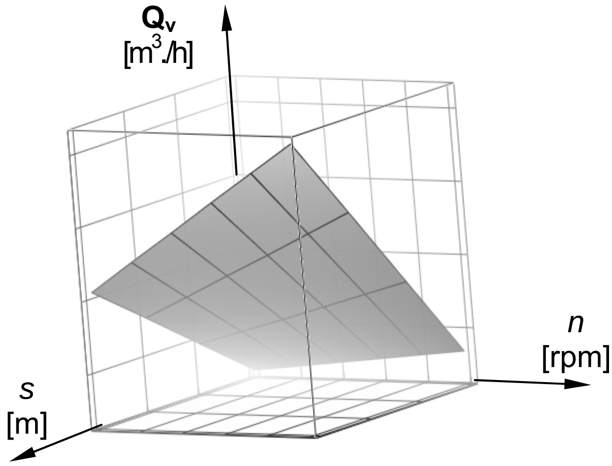


Fig. 3. Variation of the press flow rate

The theoretical volume of the material displaced by the auger spire is:

$$V_{te} = \frac{\pi}{4} \cdot (D^2 - d^2) \cdot (s - \delta) \quad [\mathrm{m}^3] \tag{3}$$

where: s –the auger spire pitch [m]; δ – thickness of the auger spire, [m]; D – outer diameter of the auger spire, [m]; d – inner diameter of the auger spire, [m].

By replacing in relation (2) the expression of the theoretical volume given by the relation (3), it results the expression of the press volume flow rate under the form (Fig. 3):

$$Q_v = \frac{\pi}{4} \cdot (D^2 - d^2) \cdot (s - \delta) \cdot (1 - \varepsilon) \cdot n \cdot k \cdot 60 \quad [\mathrm{m}^3/\mathrm{h}] \tag{4}$$

The power necessary to operate the press can be evaluated by using the relation:

$$P_p = \frac{P_{tr} + P_{pres} + P_{fr} + P_{cap}}{\eta_{tm}} \quad [\mathrm{kW}] \tag{5}$$

where: $\boldsymbol{P_{tr}}$ – represents the necessary power for transporting the material from the feeding chamber to the exhaust head, [kW]; $\boldsymbol{P_{pres}}$ – necessary power for pressing the material, [kW]; $\boldsymbol{P_{fr}}$ – necessary power for overcoming the frictions between the auger spire and the material, [kW]; $\boldsymbol{P_{cap}}$ – necessary power for pushing the material through the exhaust space in the press, [kW]; $\boldsymbol{\eta_{tm}}$ – mechanical transmission yield (output).

Necessary power for transporting the material

Taking into account the calculus relations of the slow helical conveyors it can be written the expression of the necessary power for the proper transporting of the material along the auger:

$$P_{tr} = \frac{F_r \cdot v}{1000} \quad [\mathrm{kW}] \tag{6}$$

where: F_r – resisting force of the material advancing along the press auger, [N]; v – mean speed by which the material moves along the press auger, [m/s].

The resistant force F_r is given, on one part, by the phenomenon of outer friction between the material and the walls of the pressing chamber, and, on the other part, by the phenomenon of outer friction of the material subdued to pressing. The value of this force can be calculated by the expression:

$$F_r = q \cdot l \cdot g \qquad [N] \tag{7}$$

where: *g* – acceleration gravity acceleration , [m/ s²]; *q* – linear load (mass per linear meter of material in the press, [kg/m]; *l* – length of pressing chamber, [m].

The expression of the linear load, q, can be written:

$$q = S \cdot \psi \cdot \gamma = \frac{\pi \cdot (D^2 - d^2)}{4} \cdot \psi \cdot \gamma \qquad [kg/m] \tag{8}$$

where: ψ – coefficient of admission for the press section; *S* – area of the cross section of the pressing chamber, [m^2], γ – density of the transported material [kg/m^3].

By replacing into the relation (7) it results:

$$F_r = \frac{\pi \cdot (D^2 - d^2)}{4} \cdot \psi \cdot \gamma \cdot l \cdot g \qquad [N] \tag{9}$$

It results the necessary power for transporting the material along the pressing chamber:

$$P_{tr} = \frac{F_r \cdot v}{1000} = \frac{\pi \cdot (D^2 - d^2) \cdot \Psi \cdot \gamma \cdot l \cdot g \cdot v}{4 \cdot 1000} = \frac{\pi \cdot (D^2 - d^2) \cdot \Psi \cdot \gamma \cdot l \cdot g \cdot s \cdot n}{4 \cdot 1000 \cdot 60} \qquad [kW] \tag{10}$$

Necessary power for pressing the material

The mechanical work done for pressing the material (L_{pres}) results from the expression of the equivalent tension (stress) σ, which appears inside the pressing chamber as a result of applying on the cross surface (*S*) of the pressing chamber an equivalent pressing force (F_{pres}), so that it may be produced a reduction of the volume occupied by the material, from the initial value, V_i to the final value, V_f, as it is also shown in figure 4. Thus, the equivalent tension (stress) in the pressing chamber can be expressed as:

$$\sigma = \frac{F_{pres}}{S} = \frac{F_{pres} \cdot \Delta l}{S \cdot \Delta l} = \frac{L_{pres}}{\Delta V} = \frac{L_{pres}}{V_i - V_f} \qquad [Pa] \tag{11}$$

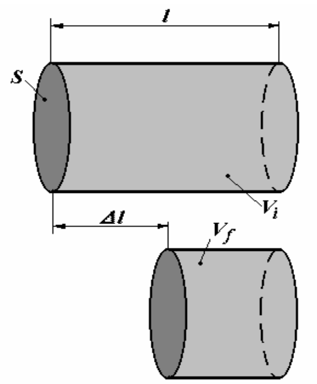


Fig. 4. Variation of the material volume in the pressing process

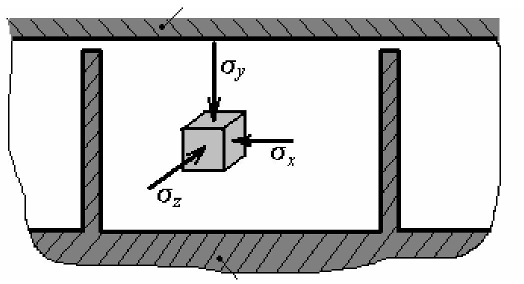


Fig. 5. Elementary volume of material subdued to the pressing process

Taking into account the relation (1), it results:

$$V_f = V_i \cdot (1 - \varepsilon) \tag{12}$$

and from the relations (11) and (12) it is obtained the expression of the mechanical work done for pressing the material:

$$L_{pres} = \sigma \cdot (V_i - V_f) = \sigma \cdot [V_i - V_i \cdot (1 - \varepsilon)] = \sigma \cdot \varepsilon \cdot V_i \qquad [J] \tag{13}$$

For determining the value of equivalent tension (stress) σ, it is considered an elementary volume of material subdued to pressing, evenly loaded on each section, as in figure 5, which, the pressing process, moves only on the longitudinal direction of the press (direction x). In these conditions it may by written:

$$\begin{cases} \sigma_y = \sigma_z \\ \sigma_x = p \end{cases} \qquad (14)$$

where: p [Pa] - pressure performed by the auger, which is exerted on the material.

It is considered that the tensions (stresses) on the direction y and z appear due to the pressure oriented to the direction of material displacement, respectively:

$$\sigma_y = \sigma_z = \beta \cdot \sigma_x \qquad (15)$$

where: β - coefficient of the side pressure.

Taking into account the relation (15), it results:

$$\sigma_x + \sigma_y + \sigma_z = p \cdot (1 + 2 \cdot \beta) \qquad (16)$$

As the materials subdued to the pressing process in the food industry also contain a certain percentage of liquid substance (oil, must, etc.), it can be considered that the hydrostatic pressure law remains valid, respectively:

$$\sigma = \frac{\sigma_x + \sigma_y + \sigma_z}{3} = \frac{p \cdot (1 + 2 \cdot \beta)}{3} \qquad (17)$$

It results the expression of the mechanical work necessary for pressing the material:

$$L_{pres} = \frac{1 + 2 \cdot \beta}{3} \cdot p \cdot \varepsilon \cdot V_i \quad \text{[J]} \qquad (18)$$

respectively, the expression of the necessary power for pressing the material:

$$P_{pres} = \frac{F_{pres} \cdot v_{pres}}{1000} = \frac{F_{pres} \cdot \frac{\Delta l}{\Delta t}}{1000} = \frac{F_{pres} \cdot \Delta l}{1000 \cdot \Delta t} = \frac{L_{pres}}{1000 \cdot \Delta t} \qquad (19)$$

where: F_{pres} – pressing force [N]; v_{pres} – pressing speed, [m/s]; Δt – the time interval when the reducing of the material volume is performed from the initial value V_i to the final value V_f, [s]. The value of this time interval can be calculated depending on the rotational speed [min^{-1}] of the press auger, respectively:

$$\Delta t = \frac{60}{n} \qquad (20)$$

Taking into account the relations (18), (19) and (20), it results the expression of the necessary power for pressing the material:

$$P_{pres} = \frac{L_{pres} \cdot n}{1000 \cdot 60} = \frac{(1 + 2 \cdot \beta) \cdot p \cdot \varepsilon \cdot V_i \cdot n}{3 \cdot 1000 \cdot 60} \quad \text{[kW]} \qquad (21)$$

In reality, in the case of food industry presses, the value of the pressure, p, is not constant along the auger, having a variation which can be as that shown in figure 6.

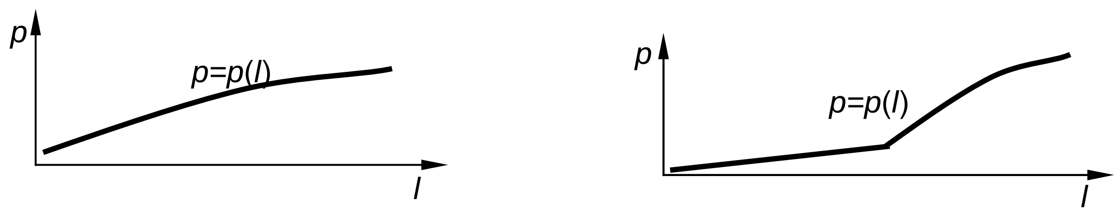


Fig. 6. Pressure variation along the pressing chamber

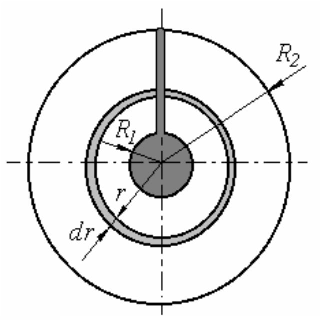
Power necessary for overcoming the frictions between the spire and material

In order to calculate the necessary power for overcoming the frictions between the auger spire and the material it is necessary that first to calculate the friction moment, which appears on the spire surface when it comes into contact with the material. For the calculus of this friction torque (moment) it is first taken into consideration an elementary ring, *dr*, situated on the auger spire on the radius *r* (Figure 7) and for the auger length suitable to a pitch, *s* it is determined ***the normal force*** exerted on the elementary ring:

$$dN = p \cdot dS = p \cdot 2 \cdot \pi \cdot r \cdot dr \tag{22}$$

The value of ***the friction force*** which appears on the surface of the elementary ring is calculated by the relation:

$$dF_f = \mu \cdot dN = \mu \cdot p \cdot 2 \cdot \pi \cdot r \cdot dr \tag{23}$$



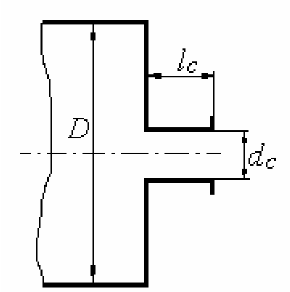


Fig. 7. Elementary ring on the auger spire

Fig. 8. End of the pressing chamber

The expression of the friction moment at the surface of the elementary ring is:

$$dM_f = r \cdot dF_f = \mu \cdot p \cdot 2 \cdot \pi \cdot r^2 \cdot dr \tag{24}$$

which, by integration, for the whole active cross surface of the auger spire, suitable to a length equal to a pitch, *s*, leads to:

$$M_f = \int_{R_1}^{R_2} \mu \cdot p \cdot 2 \cdot \pi \cdot r^2 \cdot dr = 2 \cdot \mu \cdot p \cdot \pi \cdot \int_{R_1}^{R_2} r^2 \cdot dr = 2 \cdot \pi \cdot \mu \cdot p \cdot \left.\frac{r^3}{3}\right|_{R_1}^{R_2} \tag{25}$$

respectively:

$$M_f = 2 \cdot \pi \cdot \mu \cdot p \cdot \frac{R_2^3 - R_1^3}{3} \quad \text{[Nm]} \tag{26}$$

It results the expression of the necessary power for overcoming the friction between the auger spire and the material:

$$P_{fr} = \frac{M_f \cdot n}{9550} = \frac{2 \cdot \pi \cdot \mu \cdot p \cdot \left(R_2^3 - R_1^3\right) \cdot n}{3 \cdot 9550} \quad \text{[kW]} \tag{28}$$

Necessary power for pushing the material through the exhaust space

For pushing the material through the exhaust space from the end of the pressing chamber the consumed power is:

$$P_{cap} = \frac{F_c \cdot v_{cap}}{1000} = \frac{F_c \cdot \frac{\Delta l_c}{\Delta t}}{1000} = \frac{F_c \cdot \Delta l_c}{1000 \cdot \Delta t} = \frac{L_c}{1000 \cdot \Delta t} = \frac{L_c \cdot n}{1000 \cdot 60} \quad \text{[kW]} \tag{29}$$

where: F_c – resistant force to push the material through the head of the pressing chamber,

[N]; v_{cap} – the speed of the material through the head of the pressing chamber, [m/s]; l_c – exhaust canal length, [m].

The necessary mechanical work to push the material through the exhaust space (Fig. 8) at the end of the pressing chamber L_c is calculated as:

$$L_c = F_c \cdot l_c = p \cdot A_c \cdot l_c = p \cdot \frac{\pi \cdot d_c^2}{4} \cdot l_c \qquad \text{[J]} \tag{30}$$

It results the expression for the calculus of power P_{cap}:

$$P_{cap} = \frac{p \cdot \pi \cdot d_c^2 \cdot l_c \cdot n}{4 \cdot 1000 \cdot 60} \quad \text{[kW]} \tag{31}$$

APPLICATION

On the basis of the mathematical model developed in this study, in figure 9 it is shown the variation of the component parts of the power necessary for operation in the case of a press from the oil industry. The main data taken into consideration for the modelling are: the variable auger rotational speed (n=15÷40 min^{-1}), the variable pressure inside the pressing chamber (p=50·10^5÷200·10^5 Pa), the diameter of the pressing chamber (D=200 mm), the diameter of the auger shaft (d=100 mm).

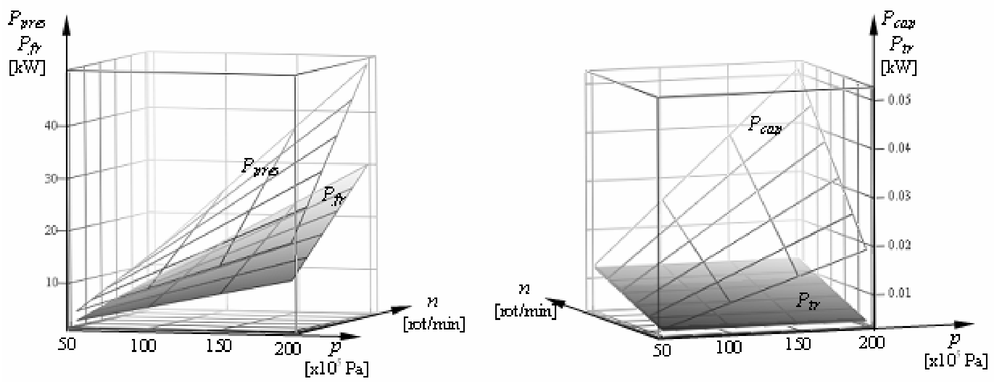


Fig. 9. Power variation depending on pressure and auger rotational speed

CONCLUSIONS

The mathematical model, created in this paper, allows high precision determination of the functional parameters and of the necessary power for operating the presses in food industry. In figure 9 it can by noticed that the necessary power for the proper pressing P_{pres} is the highest, being followed by the necessary power for overcoming the frictions between the auger spire and the material subdued to pressing P_{fr}. The values for the necessary power to push the material through the exhaust space P_{cap}, as well as the power for the material transport through the pressing chamber P_{tr}, are much lower than P_{pres} and P_{fr} *powers*, being possible to even be neglected.

REFERENCES

[1]. **Biriş S.Şt., Vlăduț V., 2004,** *Calculus elements for the mechanical continuous presses in food industry*, Buletinul Institutului Politehnic din Iaşi, Secția: Construcții de maşini, Tomul L (LIV), Fascicula 6B2, (ISSN 1011-2855), pg. 77-83.

[2]. **Ioancea L., Dinache P., Popescu Gh., Rotar I., 1986,** *Machinery, Implements and Installations in Food Industry*, Ceres Publishing House, Bucharest 1986, page 130÷147.

ABOUT THE AUTHORS

S.Şt. Biriş, "Politehnica" University of Bucharest, 313 Splaiul Independentei 060042 Bucharest, Romania, E-mail: sorinstefanbiris@yahoo.com

M. Mariana, “Politehnica” University of Bucharest, 313 Splaiul Independentei 060042 Bucharest, Romania, E-mail: maneamaryana@yahoo.com

N. Ungureanu, “Politehnica” University of Bucharest, 313 Splaiul Independentei 060042 Bucharest, Romania, E-mail: nicoletaung@yahoo.com

M. Tudosie, “Politehnica” University of Bucharest, 313 Splaiul Independentei 060042 Bucharest, Romania, E-mail: tudosie_elenamadalina@yahoo.com

V. Vlăduț, National Institute of Research-Development for Machines and Installations Designed to Agriculture and Food Industry Bucharest, 6 Ion Ionescu de la Brad, sect. 1, Bucharest, Romania, valentin_vladut@yahoo.com