OPTIMIZATION OF ENERGY CONSUMPTION BY MIXING LIQUIDS USED IN THE FOOD INDUSTRY
/
OPTIMIZAREA CONSUMULUI ENERGETIC LA MALAXAREA UNOR LICHIDE UTILIZATE IN INDUSTRIA ALIMENTARĂ

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ABSTRACT
The paper-work presents a series of theoretical and practical aspects connected to the method of approaching the energetic study of mechanical blenders with applications in food industry. The mathematical shaping and the development of studied cases were accomplished for Newtonian food liquids. The presented method can be applied for the projection and for the accomplishment of blenders for Newtonian liquids in food industry, with or without the observance of similitude conditions.

REZUMAT
Lucrarea prezinta o serie de aspect teoretice si practice legate de metoda de abordare a studiului energetic al malaxoarelor mecanice cu aplicare in industria alimentara. Punerea sub forma matematica si dezvoltarea cazurilor studiate a fost facuta pentru lichidele alimentare Newtoniene. Aceasta metoda poate fi aplicata pentru proiectarea si realizarea de malaxoare pentru lichidele Newtoniene in industria alimentara, cu sau fara respectarea unor conditii similare.The paper-work presents a series of theoretical and practical aspects connected to the method of boarding the energetic study of mechanical blenders with applications in food industry. The mathematical shaping and the development of studied cases were accomplished for Newtonian food liquids. The presented method can be applied for the projection and for the accomplishment of blenders for Newtonian liquids in food industry, with or without the observance of similitude conditions.

INTRODUCTION
Mixing of is one of the most well known procedures in food industry, because it influences the expected result of different stages of processing.

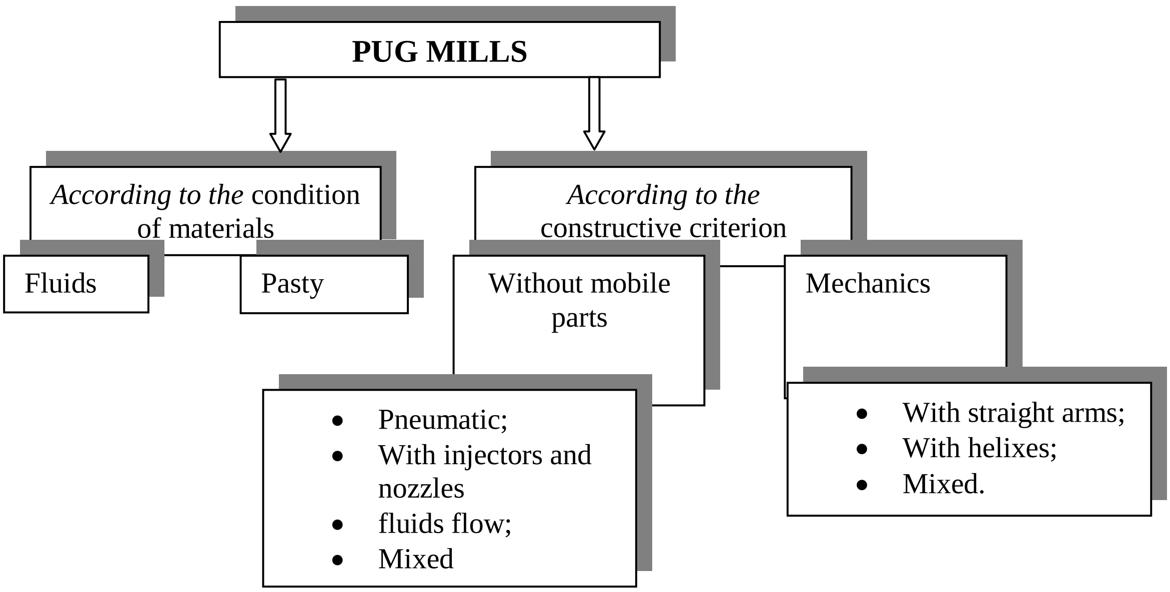

Fig. 1 -Mixers classification
(Banu, C. et al, 1998; Luca G., 1978)

The main purpose of mixing is homogenization. This takes place by submitting all the components of an assembly of motions, finally resulting in the transformation of particles' disposal and their dispersal in the blending mass.

Homogenization also manifests by reducing both concentration gradients and of temperature.

We distinguish mixings in liquid phase, with liquid-gas phase, gas-solid, liquid-solid etc.

The variety of used stirrers in food industry is considerable. In figure 1 is shown a classification of stirrers according to the state of materials subjected to mixing and respectively with their structure and driving.

MATERIAL AND METHOD

The influenced factors of mixing process

The knowledge of influenced factors upon the mixing process is important to the optimization of power consumption.

The most important factors which influence the mixing process and also its efficiency are:

- the nature of introduced materials and of resulted products as a result of mixing operation;
- the way of performing the mixing operation.

Taking into consideration that the main subject of the present paper are fluids, we can classify them in two major groups as follows: Newtonian and non Newtonian fluids. In the first category we can classify gases and Newtonian liquids, and in the second one the liquids and the non Newtonian pasture. The main properties which influence Newtonian fluids are: density, viscosity, diffusion and reciprocal solubility. The non Newtonian ones are influenced by: density, viscosity displayed most of the time through consistency and cohesion. Generally, the pasty materials have an increased consistency and cohesion and thus they significantly influenced the mixing process.

From a hydrodynamic point of view, mixing consists in realization of a turbulent motion as a rule. In the case of Newtonian food fluids, the turbulence results from a forced convection which is obtained through an efficient motion of fluid.

In the mixing process the type of flowing and the geometrical configuration where takes place the flowing can be considered important factors. It is very important the existence of the conditions created by the turbulence when the fluid slips with different momentary velocities.

It is known the fact that the nature of flowing in a mixer is determined on the basis of modified Reynolds criterion in which the fluid velocity (in the case of mechanical mixers) is estimated as a marginal velocity at the exterior end of the machine which is in a motion of rotation and the diameter of the rotary machine is adopted as a distinctive length. In the case of mixing, the limit of laminated flowing experimentally determined is Re = 10...20.

The velocity fluctuation can be considered as being momentary value of rotational motion. Thus, it results two types of turbulence: isotropic and non isotropic.

In the case of isotropic turbulence, the velocity fluctuations have an equal probability in all the directions. Each of one of these velocities has, at any moment, the same number of positive and negative values.

The non isotropic turbulence is a state in which the velocity fluctuations are neither equal nor probable and they don't have an equal size in all directions.

Prandtl has introduced as a measure of turbulence a size named mixing length. It represents the measure of the distance which a swirl covers in the surrounding fluid from a layer in motion until its velocity becomes equal with the environment, and loses its personality. The mixing length is as much bigger as the turbulence is more intense. It is not constant n the in the whole mass of fluid.

The mixing length, l_a is obtained from Prandtl equation and has the expression: *(Banu, C. et al, 1998; Bratu, E. et al., 1984)*

$$l_a = \sqrt{\frac{\sigma_t}{\rho}} \frac{1}{\frac{dv}{dy}} \tag{1}$$

where:

σ_t - tangential tension of turbulence;

ρ - fluid density;

dv/dy - the velocity gradient in the considered point.

The equipment where the mixing is produced influences the process through the connection elements with the shape and the size of the pot, the mixing device and its position towards the pot.

The mixing device must work out in the pot a shearing force big enough so that to result limit layers as thin as possible, essential to turbulence. At the same time the mixing device must attract the new product in the area of high velocities.

Another factor which influences the process of mixing is the size of the pot or the quantity of processed material. The most striking results are observed in case of mixers with desultory operation. It is recommended that in such situations to be used stirring devices with low capacities.

RESULTS

Elements of dynamics specific to mechanical mixers, with arms

These types of mixers realize the homogenization of raw material with the help of some mobile elements named: arms, blades, propellers, anchors, etc.

In the case of liquids, the mechanical mixers produce a certain working conditions of flowing.

According to the way in which device stirring conveys the liquid motion, it has developed two categories of machines:

- machines which convey the quantity of motion by stress shearing, so that this transmission to be made to a right angle towards direction of motion stirring device.
- machines which convey the quantity of motion through the pressure of blades upon the liquid, that is in the direction of motion of stirring device.

The latter type is the most frequently used. All the stirring devices with blades are part of this category. The rotary blades exert a pressure upon the liquid bulling a part of it in the environment, starting at the same time a rotating motion in the liquid. Also, behind the blades is created a diminishing of pressure allowing to attract an important part of the liquid involved in the mixing process. The liquid brought creates some vortex flows. Due to the increase of speed rotation, the liquid between the blades is submitted to some centrifugal forces, which create in the end its radial jumping-up. This liquid penetrates in the surrounding layers through a transfer quantity of motion. Then it follows an increase of section cross of liquid current and slow loss of velocity at the same time with the increase of the distance towards the blade.

Regarding the main directions of current lines we notice three types of flowing *(Foucault S. et al, 2005; Rayner M., Dejmek P., 2015):*

- tangential flowing where the liquid flows in parallel with the paddle direction;
- radial flowing where the liquid is removed through centrifugal forces in a radial direction towards the rotary axis;
- axial flowing in which the liquid penetrates the stirring device and removes itself from it according to parallel direction with the rotary axis.

In the case of stirring devices with perpendicular arms on the rotary axis, the stirring devices are located central towards the pot in general.

As a consequence of some series of experimental tests, for a stirring device which scheme is presented in figure 2, we observed that for a proper working we must respect the followings rapports of basis dimensions:

- d/D = 0.5…0.9;
- h/d=0.08…0.12;
- H/D=0.8…1.3
- H1/d=0.05…0.3

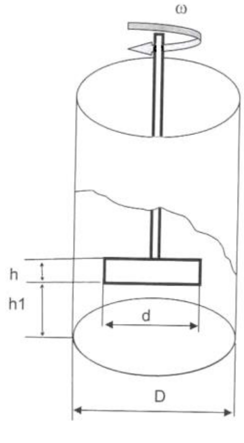

Fig.2 - The mixer scheme with assured similarity

It is recommended a diversity of peripheral velocities of 1.25…2.5 m/s in function of the product *(Maa Y.F., Hsu C., 1996; Verma A. K, 2014)*.

In order to find out the consumption of power used for mixing up Newtonian fluids in food industry, we start from Newton equation written for the elementary force exerted by the surface element dA upon the liquid in the regime period:

$$dF = \xi \cdot \frac{v^2 \cdot \rho \cdot dA}{2} \tag{2}$$

where:

ξ is the dimensionless resistance coefficient;

v – motion velocity of a certain point of the arm surface;

ρ - specific mass of liquid;

dA - elementary projection of area of the motion blade on straight-down plane on direction of motion.

If we consider the blade from figure 3 we can write:

$$\begin{aligned} dA &= h \cdot dx; \\ v &= 2.\pi.n.x; \end{aligned} \tag{3}$$

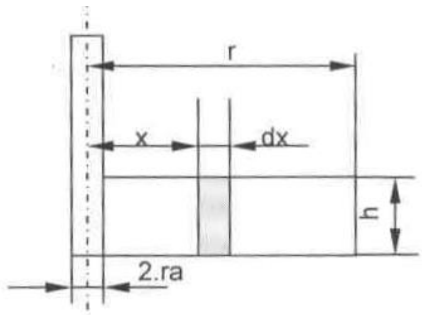

Fig. 3 - The scheme for the differential calculation of straight paddle

On the whole arm of the blade equation (2) becomes:

$$F = \xi \cdot \frac{(2 \cdot \pi \cdot n)^2}{2} \cdot \rho \cdot h \cdot \int_{ra}^{r} x^2 \cdot dx \tag{4}$$

If we consider that the starting point of application of resulted forces is at half of arm's width and the distance x_0 from ax, it results:

$$x_0 = \frac{\int x \cdot dF}{F} \tag{5}$$

Power can be written in a first stage:

$$P_1 = F \cdot v_0 \tag{6}$$

Where v_o is the velocity point of application of resulted forces:

$$v_0 = 2 \cdot \pi \cdot n \cdot \frac{\int x \cdot dF}{F} \tag{7}$$

Expression of theoretical consumed power becomes:

$$P_1 = \xi \cdot \rho \cdot h \cdot \pi^3 \cdot n^3 \cdot (r^4 - r_a{}^4) \tag{8}$$

Because r_a is incomparable less than *r*, it can be neglected towards this one. Also if we consider *2.r=d* and *h/d =a*, with a unique constant ξ' we obtain:

$$P_1 = \xi' \cdot \rho \cdot n^3 \cdot d^5 \tag{9}$$

The experimental unique constant ξ' depends on Reynolds modified criterion:

$$\xi' = \frac{c}{Re_M^m} = \frac{c}{\left(\frac{n \cdot d^2}{\nu}\right)^m} \tag{10}$$

Introducing this expression in the power equation given by the relation (9) it results:

$$P_1 = c \cdot \rho \cdot \nu^m \cdot n^{3-m} \cdot d^{5-2 \cdot m} \tag{11}$$

Because of the fact that in many situations is more likely to use the equation in function of dynamic coefficient of viscosity η, we write: *(Banu, C. et al, 1998; Bratu, E. et al., 1984; Loncin M., 1979).*

$$P_1 = c \cdot \eta^m \cdot \rho^{1-m} \cdot n^{3-m} \cdot d^{5-2 \cdot m} \tag{12}$$

The last two expressions of the consumed power used for mixing are used for the classical model presented in figure 2 and 3, meaning in the case of satisfied similarity.

The constants c and m are experimental and they can be found in tables from literature of specialty.

In the situations in which the stirring device doesn't correspond to geometrical features of similarity given by the results of experimental essays, we correct them by applying multiplication factors of power expression.

We observe two cases for which the multiplication factors are *(Banu, C. et al, 1998; Loncin M., 1979)*:

a. Stirring device with paddles and non satisfied similarity:

$$K = \left(\frac{D}{3 \cdot d}\right)^{1,1} \cdot \left(\frac{H}{D}\right)^{0,6} \cdot \left(\frac{4 \cdot h}{d}\right)^{0,33} \tag{13}$$

b. Stirring device with propeller or turbine and non satisfied similarity:

$$K = \left(\frac{D}{3 \cdot d}\right)^{0,93} \cdot \left(\frac{H}{D}\right)^{0,6} \tag{14}$$

These relations can be applied in the conditions: D/d=2.5…4, H/D=0.6…1.6, h/d=0.2…0.67 and h1/D=0.2…0.5.

The programme demonstration and the presentation of results

Based upon the mathematical model presented above there were analyzed the power consumption at mixing for milk and for saccharose solution.

For milk we used the following constants:ρ=1032,6 kg/m^3, η=0.001804 Pa.s and for the saccharose solution of 30%: ρ=1448.5 kg/m^3, η= 3.187 Pa.s la 20^{0}C.

The other constants and geometrical dimensions of stirring device were chosen in this way: c=6.8, m=0.2, d=0,3 respectively 0.4 m, D=3.8.d, H=3.5.D, h=0.4.d and n=1.25…2.5m/s. *(Banu, C. et al, 1998; Loncin M., 1979; Maa Y.F., Hsu C., 1996; Terada K. et al, 1998).*

In order to achieve a comparative analyze we initiate the following working program shown in figure 4.

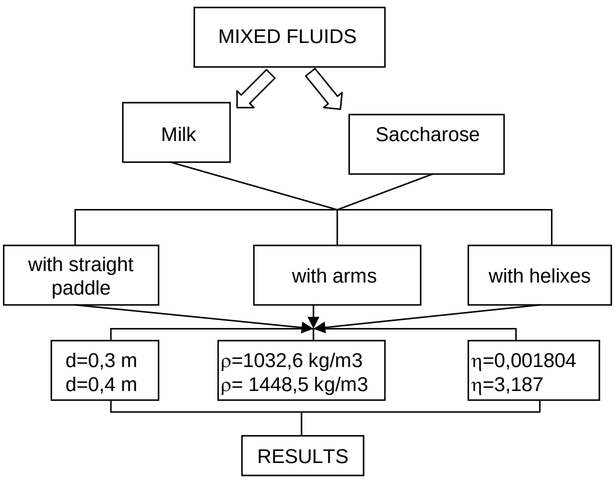

Fig. 4. The working programme for the comparative analysis

From the point of view of types of constructive stirring devices were analyzed three specific cases:

- classic mixer with straight paddles and respected the similarity conditions;
- mixer with straight paddles which doesn't correspond to imposed similarity conditions;
- mixer with propeller which doesn't correspond to imposed similarity conditions.

For each case it was traced the power variation of mixing depending on revolution, according to model presented in figure 5. , where index 1 corresponds to milk mixing with rotor of 0.3 m diameter, index 2 for saccharose solution with a concentration of 30% and a rotor with the same diameter , index 3 for milk and a rotor of 0.4 m diameter, and index 4 for saccharose solution and a rotor with the same diameter.

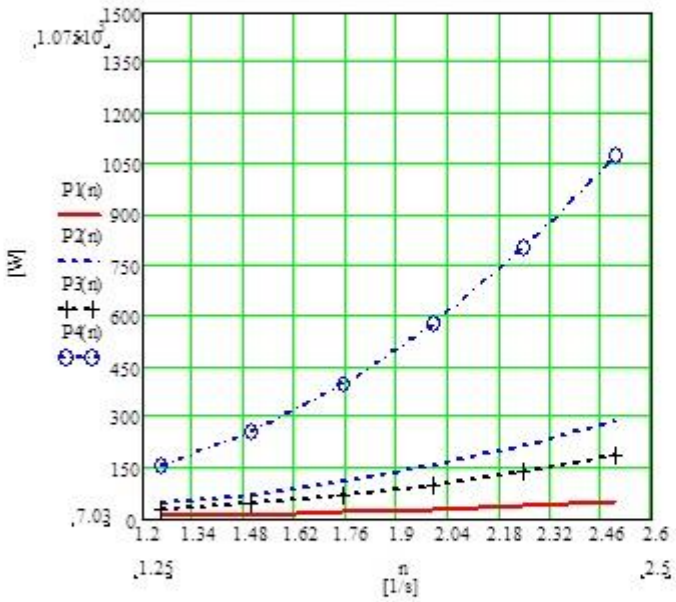

Fig. 5 - The variations of consumed powers depending on turning round

We can observe an important increase of consumed power in case 4, also at a minimal revolution and also to the maximum one taken in consideration.

In order to be able to compare the evolutions of consumed powers at proper mixing, we draw the diagrams from figures 6 and 7.

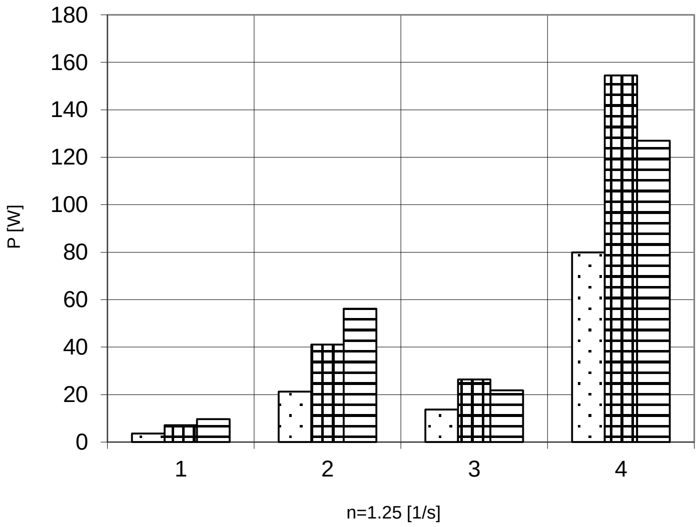

Fig. 6 - The variations of power consumption at minimum turning round

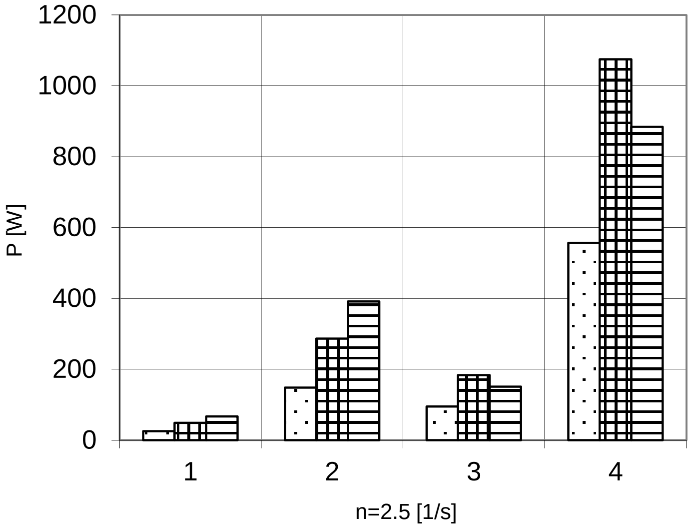

Fig. 7 - The variations of power consumption at maximum turning round

In figure 6 we observe the evolution of consumed powers at a revolution of 1.1 rot/s and in figure 7, at a revolution of 2.5 rot/s.

CONCLUSIONS

The four power variations were grouped in three certain variants: one variant for mixer with straight paddles and were respected the similarity conditions, one for the mixer with arms and conditions of similarity were unconsidered finally one for the mixer with propeller and conditions of similarity were also unconsidered. It can be observed that the minimal power is consumed (irrespective of revolution) at the mixer with straight paddles (case a). For case b, the mixer with arms and unconsidered similarity the power consumptions are much more increased to the maximum recommended values of revolution, going beyond over the values for the mixer with propeller .

To these consumed powers we add about 10…20% for the pots with rugged walls, about. 10% for the hydraulic resistance created in laggings, up to 100% for the existence of thermic treating coil and the consumed power in transmission depending on the type and its complexity.

For other types of mixers than the ones analyzed above, the geometrical features and the recommended constants are presented in table 1.

Table 1

The geometrical features and the recommended constants

Den. no.	Mixer type	Constants		Observations
		c	m	
1.	With two paddles in vertical position	111 14.35 6.8	1 0.51 0.20	Re<20; h/d=0.885; D/d=2; H/d=2; h1/d=0.36 10^2<Re<5.10^4; h/d=0.885; D/d=2; H/d=2; h1/d=0.36 Re>5.10^4; h/d=0.25; D/d=3; H/d=3; h1/d=0.33
2	With two arms inclined down to 45^0	4.05	0.20	h/d=0.25; D/d=3; H/d=3; h1/d=0.33
3	With four arms in vertical position	8.52	0.20	h/d=0.25; D/d=3; H/d=3; h1/d=0.33
4	With four arms inclined down to 45^0	5.05	0.20	h/d=0.25; D/d=3; H/d=3; h1/d=0.33
5	With four arms inclined up to 45^0	4.42	0.20	h/d=0.25; D/d=3; H/d=3; h1/d=0.33
6	With six arms in vertical position	12.50	0.25	h/d=0.066; D/d=1.11; H/d=1.11; h1/d=0.11
7	Anchor with two arms	6.2	0.25	h/d=0.066; D/d=1.11; H/d=1.11; h1/d=0.11

REFERENCES

[1] Banu C., Nicolau A., Barascu E., Stoica A., (2002), *Engineer's Manual of food industry (Manualul inginerului de industrie alimentară)*, Technical Publishing House, Bucharest, ISBN 937-31-2071-5;

[2] Bratu E. et al., (1984), *Unitary operations in chemical industry*, vol.II, (*Operaţii unitare în industria chimică*), Technical Publishing House, Bucharest;

[3] Foucault S., Ascanio G., Tanguy P.A. (2005), Mixing Times in Coaxial Mixers with Newtonian and Non-Newtonian Fluids, *Industrial & Engineering*, ACS Publications;

[4] Sahu J.K., (2014), *Introduction to Advanced Food Process Engineering,* CRC Press, Taylor & Francis Group 6000 Broken Sound Parkway New York;

[5] Loncin M., (1979), *Food Engineering,* Acad. Press, N.Y., London;

[6] Luca G. (1978), *Problems of operations and machines in food industry* (*Probleme de operaţii şi maşini în industria alimentară*), Technical Publishing House, Bucharest;

[7] Maa Y.F., Hsu C., (1996), Liquid-liquid emulsification by rotor/stator homogenization, *Journal of Controlled Release*, Volume 38, Issues 2–3, pp.219-238;

[8] Rayner M., Dejmek P., (2015), *Engineering Aspects of Food Emulsification and Homogenization,* CRC Press, London/U.K.;

[9] Terada K. et al, (1998), Characterization of the Mechanical behaviors of Solid Fluid Mixture by the Homogenization Method, *Computer Methods in applied Mechanics and Engineering*, Volume 153, Issues 3-4, pages 223–257;

[10] Verma A., K, (2014), *Process Modelling and Simulation in Chemical, Biochemical and Environmental Engineering*, CRC Press, Taylor & Francis Group. U. New.