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ANALYSIS AND ECO-TECHNOLOGICAL EVALUATION OF A NEW CONCEPT OF DOUGH MIXING, KNEADING

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Abstract

The work shows the assumptions, and the bases of analyses and evaluation of new eco-technological method for dough mixing, kneading. The main goal was to achieve high quality of the product, efficiency and safety of the process and product of hydrokinetic mixing, kneading. In result of the carried out research indicators have been achieved, which used for assessment of the mixer prototype operation, confirmed its high eco-technological value for operation in given technological and laboratory conditions.

***Keywords**: quality, efficiency, dough mixing*

1. Introduction

A torque converter mixer is a hydraulic system characterized by a rotational motion which is used for dosing and mixing components, e.g. flour with water, whereas the state of dosing and mixing depends on the rotor of the stator wheel (slat stator, also called "hockey") and is featured by the pump and turbine torque value and angular velocity changes.

The energy of the working fluid is used for elementary dosing and mixing. It is usually water. The analysis and evaluation cover the design and operation of the torque converter mixer and were performed on the basis of dimensionless characteristics, according to the results of adequate measurements. Dimensionless characteristics of the product quality, efficiency of the process, the process and product safety are dependencies of quantities, characterizing dosing-mixing properties, on kinematic and dynamic transmission.

The assumed satisfactory states of mixing, kneading (SP_M) are accomplished according to the old or the new concept, in known and unknown technological conditions (W_K, nWk), which are identified, matched, analyzed, investigated and evaluated by the designer-constructor.

The purpose of this research is to analyze and evaluate technological conditions of a new hydrokinetic mixer (*nWk*) by means of technological indicators of the product quality, the process efficiency and environmental estimators of the process safety as satisfactory states of mixing assumed to be reached (SP_M).

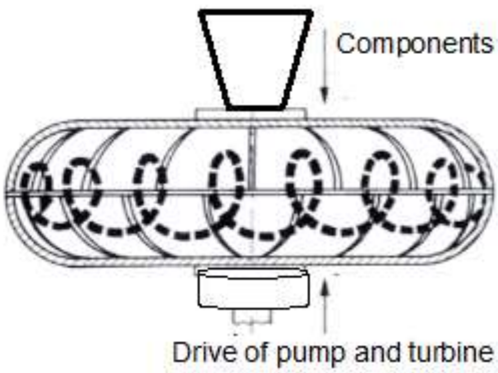
2. Presentation of the concept and its initial evaluation

Creative activity – within the space of innovativeness of design conceptual solutions – involved identification of dosing- mixing solutions with the use of available devices, machines, and systems, as well as - providing original concepts of problem solutions.

Torque converter mixer is the answer and conceptual solution to the problems connected with the mixing product quality, the process efficiency, speed of mixing, and above all, due to a close working space – it reduces dusting and carries out the process with low power demand per efficiency unit. Dosing-mixing, takes place between the blades of the pump-turbine depending on the rotational speed and the rotor space filling degree, with optimal pressure, feed control and zero dusting.

One of the way to find a solution is presented in table 1 along with an initial, expert assessment of the task.

Tab. 1. Universal variables and their indicators for eco-technological evaluation of the innovative mixing concept of hydrokinetic mixing [18]

<table>
<tr><th>No.</th><th>Idea, concept</th><th>Expert evaluation</th></tr>
<tr><td>1.</td><td>

Hydrokinetic dosing-mixer. Dosing - mixing takes place between the blades of a pump-turbine depending on the rotational speed and the rotor space filling degree with optimal pressure and no space dusting.</td><td>
<table>
<tr><th>Indicator of a variable</th><th>Evaluation*</th></tr>
<tr><td>Water pressure</td><td>6</td></tr>
<tr><td>Expenditure of water flow</td><td>6</td></tr>
<tr><td>Flour expenditure</td><td>3</td></tr>
<tr><td>Temperature</td><td>3</td></tr>
<tr><td>Indicator of mixing</td><td>6</td></tr>
<tr><td>Energy consumption</td><td>3</td></tr>
<tr><td>Concept evaluation no.7</td><td>27</td></tr>
</table>
</td></tr>
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*- *0 negative evaluation eliminates the concept!*
Evaluation was performed on the basis of indicators, criteria based subjective assessment, with the use of four evaluation values: 0 – negative, excluding a concept from further consideration 1- merely acceptable, 3 – satisfactory, 6 – excellent for a potentially optimal solution.

In the upper part of the device there are systems for dosing components: flour, yeasts, additives, water, air which are fed in appropriate portions to the mixing chamber formed from the pump and turbine housing, according to the principle of hydrokinetic devices (clutches, gears).

3. Indicators, technological and ecological criteria

A scheme of a simple single-range torque converter mixer, ”conceptually” isolated from a technological system, is presented in fig 1. Such a torque converter mixer consists of three basic components: rotor of a turbine pump (1) and the turbine rotor (2) with overlapping axes of rotation and a coaxial immovable rotor of the stator wheel (3). Their shape is usually similar to a torus filled with fluid. Each of the rotors is equipped with blades. They are used to change velocity vector of the dosed and mixed substance (flour with water and dough components) flowing through the inter-blade channels, subsequently changing its momentum. The momentum changes are accompanied with an impact of the dosed-mixed substances on the rotors blades, in effect of which a mixture is created and torque occurs on each of them.

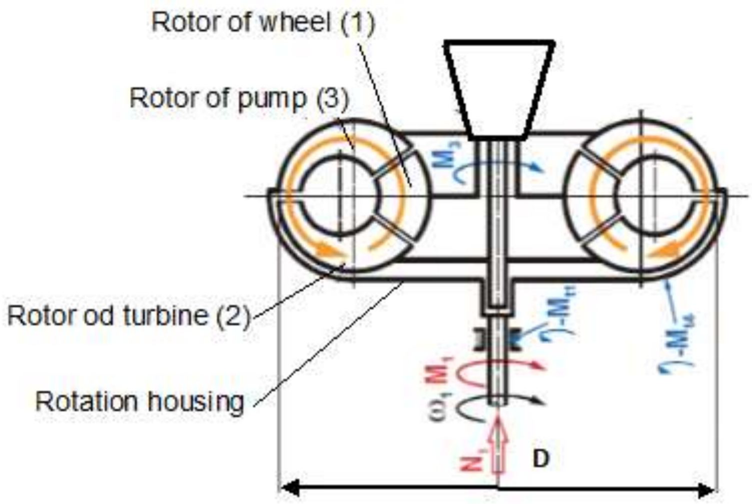

Fig. 1. Scheme of one range torque converter mixer

The input shaft of the torque converter mixer, with structure corresponding to the scheme shown fig.1, is connected with the pump rotor by means of a rotating housing. Blades of this rotor force circulation of working mass of the torque converter mixer (powdery, fluid, semifluid etc.). Then, the rotational motion mechanical energy supplied to the input shaft is converted into kinetic energy of the dosed-mixed components. The input shaft of the torque converter mixer is connected with the turbine rotor. On the blades of the rotor kinetic energy of the substance is converted fragmentarily into mechanical energy of the rotational motion. The wheel is an element needed to adjust dosing-mixing intensity and the value of torque between the input and output shafts of the torque converter mixer. It has also a shape of a rotor, however it is immovable. The substance flowing between the wheel blades undergoes momentum changes in result of the velocity vector operation line change forced by curvature of the blades. The torque which occurs on the blades is transmitted through a sleeve of the wheel onto immovable parts of the torque converter housing. Kinematic transmission of the torque converter mixer is defined as a ratio of the output shaft (turbine shaft) angular velocity ω_2 to the input shaft (the pump shaft) angular velocity ω_1, or as a ratio of respective rotational speeds n_2, n_1:

$$i_k = \frac{\omega_2}{\omega_1} = \frac{n_2}{n_1} \tag{1}$$

Dynamic transmission of the torque converter mixer is defined as a ratio of torque M_2, which is transmitted from the input shaft of the torque converter mixer to the remaining part of the dosing-mixing system, to torque M_1 which drives the input shaft:

$$i_d = \frac{M_2}{M_1} \tag{2}$$

Balance of the torque converter mixer in the fixed rotational motion requires the sum of external moments affecting the elements of the mixer, to be equal to (fig. 1) zero:

$$M_1 + M_3 - M_2 + \sum M_t = 0 \tag{3}$$

where:

M_3 – torque affecting the wheel from its mounting,

ΣM_t – sum of the torque converter mixer torques, such as moments of friction resistance M_{t1}, M_{t2}, M_{t3} in bearings of the shafts and rotational seals and moments of ventilation resistance M_{t4} of the pump rotor and the rotating housing connected with it.

Determining moment:

$$M_2 = M_1 + M_3 - \sum M_t \tag{4}$$

from dependence (3), including the expression obtained in dependence (2), it can be said that the dynamic transmission of the torque converter mixer is described by dependence

$$i_d = 1 + \frac{M_3 - \sum M_t}{M_1} \tag{5}$$

thus, for regular work conditions of torque converter mixer $\Sigma M_t << M_1$, it can be assumed that:

$$i_d \cong 1 + \frac{M_3}{M_1} \tag{6}$$

the process of dosing-mixing is accompanied with energy dissipation. Its main cause is resistance of poppy seed dough flow through inter-blade channels of the rotors. Power N_2 received from the turbine shaft is, therefore lower than power N_1 supplied to the pump shaft. Ratio of these powers expresses overall efficiency of a torque converter mixer.

$$\eta = \frac{N_2}{N_1} = \frac{M_2}{M_1} \cdot \frac{\omega_2}{\omega_1} \tag{7}$$

It is easy to say, on the basis of dependences (1), (2) and (7), that efficiency of the torque converter mixer can be expressed in the following way:

$$\eta = i_k \cdot i_d \tag{8}$$

Torque M_1 needed to drive the pump rotor of the torque converter mixer is proportional to density of the dosed ρ_1 and mixed ρ_2 ($\rho=\rho_1+\rho_2$) fluid, the second power of angular velocity ω_1 of this rotor and the fifth power of its geometric dimensions. It results from dependencies describing the flow of fluid through the rotors of rotating machines and similarities of the dynamic flow through the rotors. The flow of working substance through the rotors of the torque converter mixer is similar in terms of dynamics for different- let them be high enough - values of angular velocity and the input shaft different loadings by torque M_2, if the value of the torque converter mixer kinematic transmission i_k remains the same. The above mentioned proportionality can thus be substituted by an equality by introducing proportionality coefficient λ_M whose value depends on kinematic transmission, referred to a dimensionless coefficient of torque:

$$M_1 = \lambda_M(i_d) \cdot \rho \cdot \omega_1^2 \cdot D^2 \tag{9}$$

where:

D – active diameter of the torque converter mixer which is the highest diameter of the dosed -mixed fluid flow in the pump rotor.

A given torque converter mixer is adjusted to operation with a given fluid, working substance whose density changes in result of temperature changes. Therefore, in the Polish literature a coefficient of moment $f_M(i_k)$ is used whose physical dimension, according to SI units, is analogical to the dimension of density. This coefficient is accepted to be dimensioned as in the below dependence:

$$f_M = \rho\lambda_M \ , \ \frac{kg}{m^3 \cdot rad^2} \tag{10}$$

The torque needed to drive the pump rotor of the torque converter mixer can thus be defined on the basis of the dependence:

$$M_1 = f_M(i_k) \cdot \omega_1^2 \ \cdot \ D^2 \tag{11}$$

It should be noted that for a given mixer – with given geometric dimensions – the value of the moment coefficient remains the same for the same value of kinematic transmission. The value of torque in the pump rotor depends only on the second power of this rotor angular velocity thereby, on the rotational speed of the motor or a subsystem of the system which drives the mixer input shaft. Thus, the process of the moment coefficient dependence on the value of kinematic transmission characterizes unequivocally the torque converter mixer in terms of value of the torque needed to drive its input shaft with a given kinematic transmission.

Dependence (6) shows, that dynamic transmission of the torque converter mixer is higher than unity for such service conditions for which the sense of torque $M_{3,}$ acting on the wheel from its mounting, is the same as the sense of torque M_1 which drives the input shaft. Dynamic transmission reaches the highest value i_{dmax} for kinematic transmission i_k = 0, when the turbine rotor is stopped (ω_2 = 0). Value i_{dmax} is called coefficient of the torque converter mixer transformation. An increase in the value of M_2 received form the output shaft causes an increase in the angular velocity of the turbine rotor and an increase in the kinematic transmission. This is accompanied with a drop in M_3 acting on the wheel and a decrease in dynamic transmission. The value of kinematic transmission, for which M_1 driving the pump rotor and M_2 received from the turbine rotor, is called kinematic transmission of coupling i_{ks}. Dynamic transmission of the torque converter mixer is then equal to unity: i_d =1. A point on the mixer characteristics corresponding to kinematic transmission of the coupling is called the point of coupling. In the interval of kinematic transmission values lower than that of coupling i_{ks} the sense of M_3 is consistent with the sense of the input torque M_1. Values of dynamic transmission is then higher than unity. In the range of kinematic transmission higher than i_{ks} the sense of torque M_3 of a one range torque converter mixer is opposite to the input torque M_1. Dynamic transmission of the one range converter mixer is then lower than unity and its efficiency decreases rapidly along with an increase in kinematic transmission.

Unit energy consumption can be determined by linking power demand with a unit of dosing-mixing, kneading:

$$E_j = \frac{N_m}{Q_m} \ , kJ \cdot kg^{-1} \tag{12}$$

where: Ej – unit energy use, J, N·m, N_M – power of torque converter mixer (mixing), W, Q – mass efficiency of mixing, $g \cdot s^{-1}$.

Ecological efficiency of dosing-mixing [7, 18]

$$e_{EKO} = \frac{\Delta E_{EKO}}{K_{EKO}} = \frac{E_{ur}}{m_{CO_2}}, \tag{13}$$

where:

e_{EKO} – indicator of ecological efficiency,

K_{EKO} – expenditures of natural resources

ΔE_{EKO} - increase in ecological benefits

E_{ur} – average yearly ecological benefit (eliminated emissions), $g_{ekw}CO_2 \cdot kg^{-1}$ of dough

m_{CO2} – average yearly expenditures of emission $g_{ekw}CO_2 \cdot kg^{-1}$ of dough.

4. Discussion of results, eco-technological solution

Water absorption of flour obtained in the laboratory – 54.5 % for 500 j.u. Consistency of the dough assumed by a technologist - 350 j.u. Conclusion: It is necessary to add 57.3 liters of water per 100kg of wheat flour for tests of 54.5% water absorbance in order to provide the assumed functional consistency (350 j.u.). The methodology for tests of '0' material assumed preparation of dough from 140 g of the tested wheat flour, 2.5 g of yeasts and 2 g of salt and 80 ml of water.

Table 2 shows mean values of kinetic transmission of the torque converter mixer as a ratio of the output shaft angular velocity (turbine shaft) ω_2 to the input shaft (pump shaft) angular velocity ω_1. Dynamic transmission of the torque converter mixer - as a ratio of torque M_2, transmitted from the output shaft further to the remaining part of the dosing-mixing system- to M_1 driving the input shaft. Efficiency of torque converter mixer - as a product of kinematic and dynamic transmission. Torque M_1 is needed to drive the pump rotor of the torque converter mixer (proportional to the mixed substance density, second power of angular velocity ω_1 of this rotor and the fifth power of its geometric dimensions). Unit energy consumption E_j – linking the power demand with efficiency unit of the substance mixing, kneading.

Tab. 2. Mean values of the dosage-mixing, mixing components/substances of flour dough

No.	Substance	Kinematic transmission	Dynamic transmission,-	Efficiency, -	Input moment, N·m	Energy consumption, $J\cdot g^{-1}$	Emisssivity CO_2 $g_{ekw}CO_2\cdot kg^{-1}$
1.	Air	0.98	0	0	144.52	0	-
2.	Water	0.92	0.11	0.10	229.33	0	-
3.	Flour	0.95	0.52	0.49	189.48	0	-
4.	Flour dough	0.87	0.96	0.84	677.50	1.7615	150

Mean values of the torque converter mixer kinematic transmission, as a ratio of the output shaft angular velocity (turbine shaft) ω_1 to input shaft (pump shaft), in the function of service loads were found to be decreasing for the considered substances: air, water, flour, flour dough (from dosing through mixing, kneading to obtain a ready structure). Neutral motion (air between pump-turbine, like for water and flour), mixing motion and kneading motion were considered to be loads. Dynamic transmission of the torque converter mixer - as a ratio of torque M_2, torque M_1 which drives the input shaft, increases in the function of service loads of the mixing and kneading motion, and reaches value close to unity for a given state of dough mixing. Efficiency, as a product of kinetic and dynamic transmission, also reaches the highest value - for the highest functional loads (flour dough). Torque M_1 of the mixer pump exhibits appropriate sensitivity to the mixed substance density changes (higher for water and lower for dry flour), under conditions of the rotor stable angular velocity (ω_1=const) and its constant diameter (D=const)). Unit consumption of energy E_j – depends on the mass productivity and appears only for flour dough mixing (E_j=1,7615 $J\cdot g^{-1}$).

In order to achieve the assumed satisfactory states **detailed problems have been solved providing better results** (by 10-40)%) than had been expected for the new, innovative technical conditions (innovative designs of machines and devices designs, new mechanical-chemical-thermal processing parameters) of the product preparation and manufacturing to reach the state assumed in the design including :

1. high quality of the product (different application ways),
2. high efficiency of the process (unit energy consumption $E_j < 100$ kJ·kg),
3. high safety of the product and process impact (zero-balance emission) (emission CO_2,150 $g_{ekw}CO_2\cdot kg^{-1}$ of dough).

It is possible by means of algorithms to find in the auto-regulatory such technical conditions: intensity of the feed dosing (q_{pi}, with specified parameters: average dimension

d_{pk}, wetness w_{pk}), velocity of angular velocity of rotors with nozzles, that the indicators of kinematic and dynamic unevenness reach values from the permissible interval: (1.44-18.36)%.

5. Summary and conclusions

To sum up it needs to be said that this research method is of universal character for: improvement of technical parameters regardless of their function and purpose; reduction of detrimental effect to the environment (natural and technological environment); extension of knowledge needed in design and construction of new engineering objects and improving the culture of their utilization.

The importance of modern metrology LABVIEW (including smart metering) and data communications in the development of systems should also be highlighted. The computer aided experimenting makes it possible to perform continuous measurements of different electrical and nonelectrical quantities (CAE standards).

The most important progress in the field of eco-technological evaluation the dosing mixing, kneading concept has been reported in data analysis techniques whose results assist designers in making decisions. Owing to the development of micro-processing systems and availability of high volume static and dynamic memories it is possible to use time consuming analytical technologies based on artificial intelligence such as neuron networks and genetic algorithms.

The assumption that methodological development needs to be based on the rules of control and compensation of experimental states turned out to be very important. It needs to be stressed that the distinctive features of the method for accomplishment of two project goals are: clearly defined goals oriented to development of innovative concepts for dosing-mixing and hydrokinetic kneading; dynamics and continuity of operation; versatility; application of advanced analytical methods; systematic verification of the achieved results.

The assumed goals have been achieved using an efficiency model of unit energy consumption, efficiency of the process for the needs of autonomous operation; selected indicators were determined experimentally: the product quality, efficiency of the process, safety of the product and process of mixing and kneading to be used in the function of adjustment to developmental activities.

Engineering of dosing-mixing and kneading is a broad issue so far dealt with on the basis of fragmentary experiences gained in technical disciplines and achievements of cognitive science. A possibility of providing a solution to vast problems of functional characteristic uniformity has been discussed (under engineering conditions).

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