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Analysis and eco-technological evaluation of micro grain supersonic milling. Part II.: Results and discussion

Introduction

In the Part I of the paper [*Flizikowski et al., 2017*] the concept and initial evaluation with indicators, technological and ecological criteria have been presented.

Results and discussion. Eco-technological solutions

The developmental research carried out in the first stage of the research included an analysis, evaluation and a description of the most important issues connected with the phenomena accompanying milling with the use of a fast-rotating disc tool with variable particle acceleration (blade projection, surface friction, working space infusion and combination of these phenomena). The investigations covered milling of micro-grain materials (polymer fillers) and variable structure of the tool (geometric, material and dynamic characteristics of the disc) – disc element– from discovering, innovation; through modernization to optimization of the process/phenomenon and its detailed design; employing milling phenomena and technologies – to achieve the maximum technological and environmental usability (including e.g. energy processing) of the innovative system/milling tool [*Bieliński and Flizikowski, 2007; Flizikowski and Bielinski, 2013*].

In successive stages: calculation and physical experiments of milling micro-grains of montmorillonite, using basic and additional efficiency tests were performed – to formulate a definition and a description of the relations between the machine input variables, methods, operation, systems, technical/environmental conditions, their indicators and the states (SP_M) assumed to be reached– functional characteristics of the innovative disc tool, milling system equipped with a working element with an envelope working at supersonic linear speed, created to be implemented in industry.

In the third stage, the investigations were connected with design-construction, manufacturing, operation through manufacture based verification, functionality, maintenance, supply and monitoring of the new solution processes in the area of micro-grain processing. Table 2 shows mean values of the aero-kinetic mill kinematic transmission as a ratio of angular velocity ω_2 of milled micro-grain ring (virtual turbine) to angular velocity ω_1 of the input shaft (real shaft of the pump).

Dynamic transmission of an aero-kinetic mill – as a ratio of torque M_2, which is the operational loading of a supersonic disc mill, to moment M_1 driving the input shaft. Efficiency of an aero kinetic mill – as a product of kinematic and dynamic transmission. Moment M_1 - necessary to drive the aerokinetic mill pump rotor (proportional to density of the mixed substance, second power of angular velocity ω_1 of this rotor and the fifth power of the rotor disc diameter). Unit energy consumption E_j – links power demand with substance milling efficiency unit of the aerokinetic mill.

For the analyzed substances: air, montmorillonite (from dosing through mixing, milling until obtainment of granulometry of a ready structure), mean values of kinematic transmission of the aerokinetic mill as a ratio of angular velocity ω_2 of the rotating, mixing and micro-grain milling ring (virtual turbine) to angular velocity ω_1 of the pump input shaft in the function of operational loading, were decreasing. The loading included: neutral motion (air between pump - turbine), mixing motion, milling motion.

Dynamic transmission of the aerokinetic mill, as a ratio of rotational moment M_2 of the substance virtual ring to moment M_1 which drives the input shaft, increases in the function of operational loadings of the mixing and milling motion and reaches the value close to unity for the grain grind.

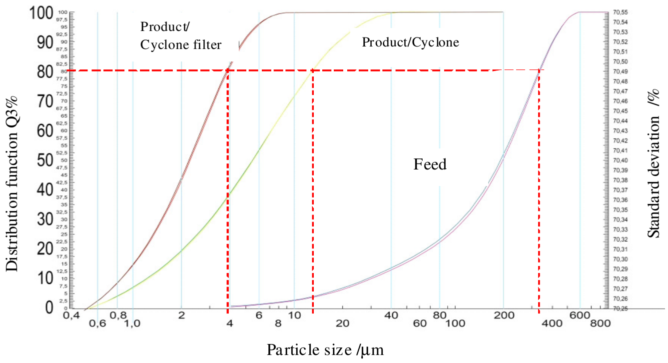

Fig.1. Granulometric diagram of montmorillonite milling product

Efficiency, as a product of kinematic and dynamic transmission, also reaches the highest value for the highest operational loadings (the chamber space highest filling with micro-grains).

Table 2. Mean values of indicators of micro grain dosing-mixing milling components/substances

Substance	Kinematic trans-mission, [-]	Dynamic trans-mission, [-]	Effi-ciency, [-]	Input mo-ment, [N·m]	Energy consump-tion, [$J \cdot g^{-1}$]	Emissions of CO_2* [$g_{ekw}CO_2 \cdot kWh^{-1}$]
"without air" (bP)	-	-	-	37,0	-	18624
Air (P)	-	-	-	102,50	-	26190
P+30% montmorillonite	0.25	0.51	0.1275	150.17	1016	27354
P+60% montmorillonite	0.27	0.48	0.1296	172.41	524	28277
P+90% montmorillonite	0.30	0,44	0,1320	178.08	365	29391

* for the research technology of energy/power supply emission equivalent 291 $g_{ekw}CO_2 \cdot kWh^{-1}$ was accepted.

Moment M_1 of the aerokinetic mill pump exhibits appropriate sensitivity to the mixable substance density changes (higher for wet and lower for dry substance), for constant angular velocity (ω_1 = const.) of the rotor and its stable diameter (D = const)). Unit energy consumption E_j – depends on the mass efficiency and appears only in micro-grain milling ($E_j = 1016\ J \cdot g^{-1}$).

To reach the assumed satisfactory states, detailed problems have been solved which provided more satisfactory (by 10÷40)%) results than those to be expected under the new technological conditions (innovative structure of machines and devices, new mechanical-chemical-thermal processing) connected with preparation and performance of processes to achieve the initially assumed satisfactory state:

– high quality of the product (different application ways),
– high efficiency of the process (unit energy consumption $E_j < 1500$ kJ·kg),
– high safety of the product (zero-emission balance) and the process (emission CO_2,101 $g_{ekw}CO_2 \cdot kg^{-1}$ of the grain product).

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Mean values of micro-grain milling granulometric indicators are presented in table 3. The used indicators of a 80% dimensional population of the input micro grains, the product and grain fineness bear features of data objectivity. At the same time they are, with maintenance of the measurement conditions cyclicity, good estimators of the granulometric state of different micro-grains.

Apart from granulometric characteristics, table 3 contains characteristics of the turbine torque, virtual ring of the work substance (air and montmorillonite) as well as milling efficiency which was determined according to the below dependence:

$$\eta_R = \frac{L_{uR}}{M_2} \tag{1}$$

where:

η_R – micro-grain milling efficiency according to an aerokinetic model,

L_{uR} – useful work of aerokinetic milling, [J, kWh],

M_2 – rotational moment of turbine, virtual ring of the milled material (air and micro grains), [N·m].

Table 3. Mean values of granulometric indicators of micro-grain milling

Substance	Assigned dimension D_{80} [μm]	Dimension of product d_{80}, [μm]	Disintegration degree λ_{80}	Moment of turbine M_2 [N·m]	Efficiency of milling η_R
P*+30% montmorillonite	346	12.55	27,55	76.5867	0.080
P+60% montmorillonite	351	15.38	2.83	82.7568	0.095
P+90% montmorillonite	357	20.85	17.12	78.3552	0.090
P* stands for air					

The highest milling efficiency $\eta_R = 9.5\%$ was reached for air filled with montmorillonite up to 60% of the dispenser space, for the input granulation $D_{80} = 351$ μm and average granulation of the product $d_{80} = 15.38$ μm (Fig.1). It is also one of the highest efficiencies of precision milling!

It has been confirmed, for disc mills with given geometric structural features, that the value of the moment coefficient remains the same for the same value of kinematic transmission.

The value of torque on the pump rotor depends only on the second power of this rotor angular velocity, thereby on rotational speed of the motor which drives the input shaft. Thus, the dependence of the moment coefficient and the value of kinematic transmission provide unequivocal characteristics of the mill in terms of value of the moment needed to drive the input shaft with a given kinematic transmission.

Consequences of application of dependence (6) which indicate that dynamic transmission can be higher than unity during the disc movement, for which the sense of reaction moment M_3, acting on the housing from its mounting, is the same as the sense of moment M_1 which drives the input shaft, have not been confirmed. It can also be said that dynamic transmission does not reach the highest value i_{dmax} for kinematic transmission $i_k = 0$, lack of substance supply when the substance ring is stopped ($\omega_2 = 0$).

Using genetic algorithms it is possible to find such technical conditions in the autoregulatory process: input dosage intensity (q_{pi}, with specified parameters: average dimension d_{pk}, wetness w_{pk}), angular velocities of the disc rotor, that indicators of kinematic inequality (i_k) and dynamic inequality (i_d) reach values from the interval of permissible values: 1.44÷18.36%.

Summary and conclusions

To sum up the research results it needs to be said that the research method is a versatile one and can be used for: modernization of engineering objects regardless of their function and purpose; reduction of damage to the natural and technological environment; improving knowledge needed in design and construction of new objects as well as increasing awareness of their proper utilization.

It should be noted that modern *LABVIEW* technology (including smart metering) and data communications play a very important role in the development of systems. They provide the possibility of continuous measurements of different electrical and nonelectrical quantities, in different facilities and they provide computer aid for experiments (CAE standards).

The largest progress in eco-technological evaluation of dosing-mixing milling concept has been reported in the field of data analysis technologies whose results assist object management in making decision. Development of micro-processing systems and availability of large capacities of static and dynamic memories enables widespread application of time consuming analytical technologies based on artificial intelligence: neuron nets, genetic algorithms.

The goal of the study involving an analysis and evaluation of technological conditions of the new designed aerokinetic mill (nWk) by means of technological indicators (1) to (11) (Part I), variables of the product quality, efficiency of the milling process and environmental estimators of safety (12) and (13), as the assumed satisfactory states of milling (SP_M), has been achieved.

The process of micro-grain milling in a disc mill with supersonic speed of the milling disc edge is accompanied with energy dissipation. Its main cause is resistance of the milled substance flow through the inter-blade ducts of the rotor disc-housing. Power N_2 received by the rotating ring of the milled substance (virtual turbine) is, due to this resistance, lower than power N_1 supplied to the pump shaft. The ratio of these powers represents overall efficiency of the aerokinetic mill.

The research and development methodology involved the milling process modeling by means of phenomena accompanying hydrokinetic coupling. Firstly, the milling phenomena were approached with a fast-rotating disc tool of variable acceleration of particles concept (blade projection, surface friction, working space infusion and combination of these ideas/phenomena) micro-grain materials (grains of polymer filler substances) in the zones of working space. Secondly – variability of the tool structure (geometric, material and dynamic characteristics of the disc) – disc system– was developed to improve innovation. Thirdly, - known phenomena and milling technologies were taken advantage of in order to achieve the highest technological and environmental usability (including, eg. energy processing) of the milling innovative system /tool.

The assumption to root the methodological development in the rules of control, regulation and compensation of experimental states turned out to be very important. It should be noted that the main distinctive features of the method developed to achieve two goals of the design are: clear definition of the goal functions including: development of an innovative idea for dosing-mixing and aerokinetic milling and application of advanced analytical methods and systematic verification of the achieved results.

The goal of the research has been achieved with the use of efficiency model, unit energy consumption, efficiency of the process for the needs of autonomous operation; selected indicators were determined experimentally, that is: the product quality, the process efficiency, safety of the product reaction and the dosing-mixing milling by using them in the function of adjustment to developmental actions.

Milling engineering is a broad field and is based on fragmentary experiments performed within technological disciplines as well as achievements of cognitive science. A possibility of solving complex problems connected with functional characteristics (on the basis of engineering) has been presented.

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