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INFORMATION TECHNOLOGY IN DESIGNING HIGH-PERFORMANCE EQUIPMENT FOR BIOMASS COMPACTING

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Abstract: *The basic principles and methods of constructing a mathematical model for the processes of particular materials processing are presented in this paper. An example of the practical application of the developed model in the technology of biomass extrusion, which is used for the production of fuel pellets, is considered. A mathematical model of the process for particular materials extrusion is developed and a new approach to the extrusion granulator unit design is offered with the developed methods taken as a basis. The effect of technological and design factors of extrusion granulator unit to the extrusion process regularity are also studied.*

Keywords: *design information technology, mathematical modeling, particulates, granulation, fuel pellets.*

1. Introduction

Food processing industry has recently faced a problem of rational use of waste products such as sunflower husk, straw, brewer's grain, wood chips, etc. It is advisable to use this waste as biomass fuel, or feed compound, etc. Transporting these materials is considered economically unjustified because of their small bulk density. This fact becomes an agent for bulk density increase of the materials through compression (briquetting, embaling, granulation, etc.) The analysis of various compression technologies showed that the granulation technology is the most rational one as it can be used for continuous product processing. It also allows obtaining the products of the highest density and versatility (biofuel, feed compounds of different fractions). Granular materials have greater storage stability and better mixture homogeneity. They also better preserve vitamins and trace elements, occupy 2-3 times less space, and are less exposed to environmental influences if compared to bulk materials. Intensification of particular materials compression processes, which recently has become most noticeable in the field of solid biofuels production, results in more stringent requirements for performance indicators of main technological systems. Therefore, the connection between both design (active zone sizes, shape and speed of the movable elements, etc.) and technological (machine performance, pressure, temperature, physical and mechanical characteristics of the material, etc.) factors should necessarily be considered when designing such machines and devices. The traditional approach to the design of this type of equipment is based on empirical

dependences and experimental experience [1] and does not allow quantifying the interference between technological and design factors of processing and structural and mechanical properties of materials. Therefore, applying the modern methods of mathematical modeling to the process of extrusion granulation of particulate materials is considered to be a topical issue.
The analysis of the recent research studies in the field of granulation technology testifies that for the effective designing of the particular technologic equipment it is necessary to take into consideration the structural and mechanical characteristics of the processed materials and in the first place their such rheological properties as elasticity, plasticity and viscosity. Works [2-3] show the principles of mathematical model construction for the granulation process of dispersed materials by extrusion. To increase efficiency of practical use of the given model it is essential to further improve it with the aim to embrace the maximum number of design and technological parameters. Taking into account the broad range of raw materials types, the problem of proper interdependence between main design and technological parameters of a given extrusion unit comes to the front when defining design properties of the appropriate equipment.

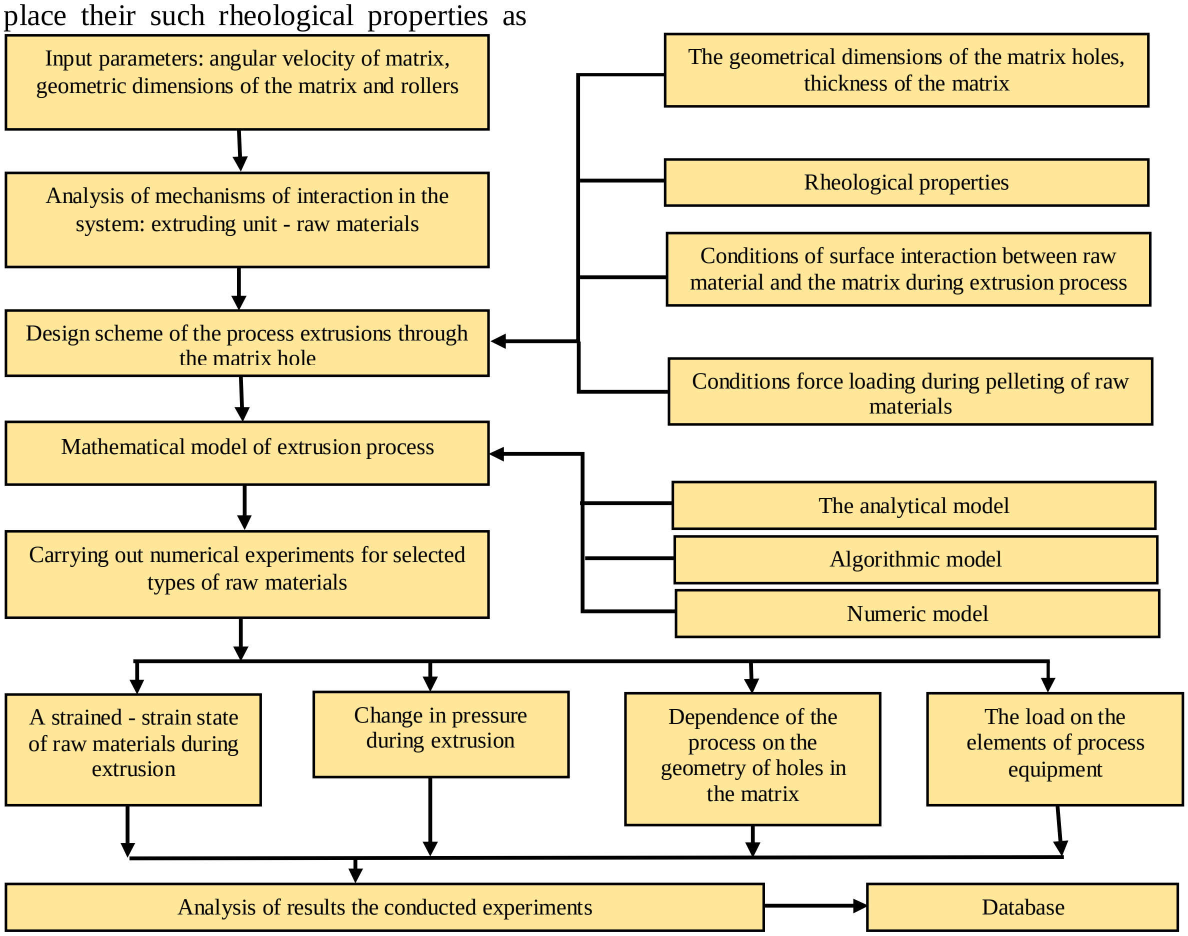

Figure 1. Information technology scheme of designing equipment for extrusion compacting.

2. Experimental

The main aim of this work is to develop the design information technology (DIT) of processing equipment for dispersed materials by extrusion as well as to use the developed (DIT) when designing an extrusion granulator unit when applying biomass granulation technology to produce fuel pellets. The article describes the (DIT) type [2]: "mathematical model - intellectual expert system - automatic design system "which is represented in figure 1. (DIT) represents technological extrusion process as a multi-component system of interconnected objects under study: raw material mass, technological equipment elements, mechanic loading, etc.

When examining particular processing technology we use the conception of introducing dispersed mass as a two-phase mixture of the porous or solid granular deformed structure with liquid or gas. To describe the behavior of dispersed mass, the notions of tension, deformation, density and also the velocity of changing these parameters were used.

As a basis of analytical model the momentum retention equation at macro-coordinates was used for:

a) a solid phase

$$\frac{\partial}{\partial t}(\alpha_1\rho_1\mathbf{u})+\text{grad}(\alpha_1\rho_1\mathbf{u}\times\mathbf{u})-\text{grad}(\alpha_1\boldsymbol{\sigma})-\mathbf{F_1}-\mathbf{F}^{(1)}=0 \quad (1)$$

b) a gas-liquid phase

$$\frac{\partial}{\partial t}(\alpha_2\rho_2\mathbf{v})+\text{grad}(\alpha_2\rho_2\mathbf{v}\times\mathbf{v})-\text{grad}(\alpha_2\mathbf{P})-\mathbf{F_2}+\mathbf{F}^{(2)}=\mathbf{0}\ , \quad (2)$$

where α_1, α_2 – volume content of solid and gas-liquid phase; ρ_1, ρ_2 – corresponding average phase density; **u, v** – vectors of average displacement speed of solid particulates and liquid correspondingly; **P** – hydrostatical pressure at a gas-liquid phase; $\mathbf{F_1}$, $\mathbf{F_2}$ – vectors of volume forces in solid and liquid phases correspondingly; $\boldsymbol{\sigma}$ – a tensor of tensions at a solid phase; $\mathbf{F}^{(1)}$, $\mathbf{F}^{(2)}$ – forces of interphase interaction.

As a result of equality $\mathbf{Pn}=-\boldsymbol{\sigma}\mathbf{n}$, at division points of inner surface of gas-liquid and solid phases (n - normal vector to the division surface) the following condition is fulfilled:

$$\mathbf{F}^{(2)}=\mathbf{F}^{(1)}=\mathbf{F}^{\mathbf{0}} \quad (3)$$

Formal addition of equation (1) and (2) describes, apparently, momentum retention at all macropoints of dispersed environment :

$$\frac{\partial}{\partial t}(\alpha_1\rho_1\mathbf{u}+\alpha_2\rho_2\mathbf{v})+\text{grad}(\alpha_1\rho_1\mathbf{u}\times\mathbf{u}+\alpha_2\rho_2\mathbf{v}\times\mathbf{v})- \\ -\text{grad}(\alpha_1\boldsymbol{\sigma}+\alpha_2\mathbf{P})-\alpha_2\mu\nabla^2\mathbf{v}-\mathbf{F_1}-\mathbf{F_2}=0 \quad (4)$$

However, when doing practical calculations, it is more convenient to consider balance momentum equations separately - in the forms of equation relating to movement of a gas-liquid and a solid phase.

If to set the force of interphase interaction in the form of

$$\mathbf{F}^{\mathbf{0}}=\mathbf{F}^{(1)}=\mathbf{F}^{(2)}=\mathbf{R}+\mathbf{P}\text{grad}\alpha_2 \quad (5)$$

and to take into account that $\alpha_1 = 1 - \alpha_2$, then the relative movement equation of the solid phase will be represented as follows:

$$\alpha_1\left(\rho_1\frac{d\mathbf{u}}{dt}-\rho_2\frac{d\mathbf{v}}{dt}\right)-\mathrm{grad}\boldsymbol{\sigma}^f-\frac{\mathbf{R}}{\alpha_2}-\alpha_1(\rho_1-\rho_2)\mathbf{G}=0\ , \qquad (6)$$

where $\mathbf{R}=\frac{\mu}{a^2}\alpha_1\alpha_2(\mathbf{v}-\mathbf{u})$ effective viscous resistance force; μ -coefficient of viscosity at a liquid phase; a – interphase friction coefficient.

The equation of relative movement of liquid phase we can describe in the following form:

$$\rho_2\frac{d\mathbf{v}}{dt}=-\mathrm{grad}\mathbf{P}-\frac{\mathbf{R}}{\alpha_2}+\rho_2\mathbf{G}\ , \qquad (7)$$

where G - vector of acceleration of the free falling.

It should be mentioned that for the processes which take place at a low pace, there are no inertial effects: $\rho_2\frac{d\mathbf{v}}{dt}=0;\ \rho_2\mathbf{G}=0$), the equation (7) represents the law of filtration within isotropic porous environment:

$$\mathbf{v}-\mathbf{u}=-\frac{a^2}{\mu\alpha_1}\mathrm{grad}\mathbf{P} \qquad (8)$$

The experimental study shows that at a small pressure gradients or filtration velocity the linear Darcy's Law acts.

$$\mathbf{v}-\mathbf{u}=-\frac{k^p}{\alpha_1}\mathrm{grad}\mathbf{P}, \qquad (9)$$

where k^p - environment permeability coefficient.

To loop a system of obtained equations (1-9), it is necessary to define the mode of solid phase deformation (determinant correlation) with corresponding spatial and temporal modes of boundary condition changes. Determinant correlations are taken within a framework of rheological model of elastic, viscous and plastic body. Besides, degree of deformation of a liquid phase is carried out by setting kinetics of volumetric phase content change, determined by filtration mechanism. (7)

Algorithmic model consists of the following main parts:

- Solution to a specified problem is based upon the principle of application of projecting and grid methods: finite elements to spatial variables and finite-differences by time argument.
- Calculated algorithms, which realize the most typical extrusion rheological processes of dispersed systems.

The developed algorithms were realized in the form of "PLAST-GRN" programming complex (digital model) [4]. Programming complex is aimed to simulate non-balanced deformation processes of two-phase dispersed structures under given technological mode.

Within the framework of the developed design information technology, to obtain fuel pellets the granulation process of dispersed masses by extrusion was considered [5].

The major impact on the granulation process is made by the granulator design (especially, the holes profile of granulator unit matrix [6,7] and the rheology of the matter being granulated

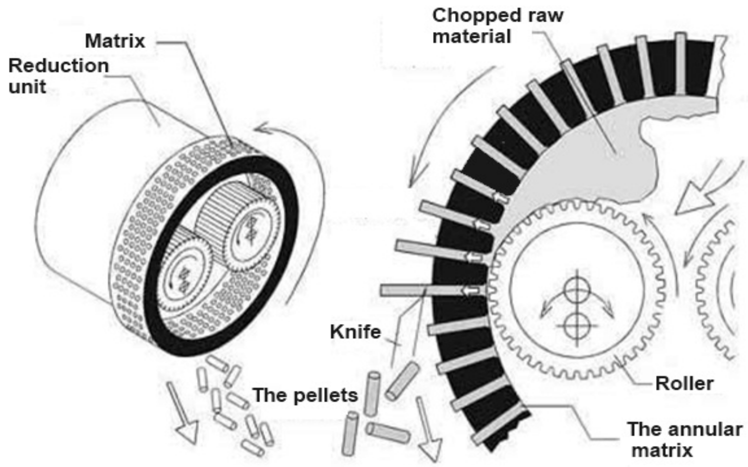

Figure 2. Granulator unit with annular matrix

Besides, one of the typical structural schemes of granulation by extrusion was considered, the one, which contains pressing roller mounted within annular matrix.

For the given structural scheme of the granulator unit it is possible to point out main parameters, which determine the production process such as roller and matrix size, the holes size in matrix, surface roughness in holes, rotation speed of granulator matrix, extrusion pressure through holes, rheological properties of the matter, productivity and quality of the finished products.

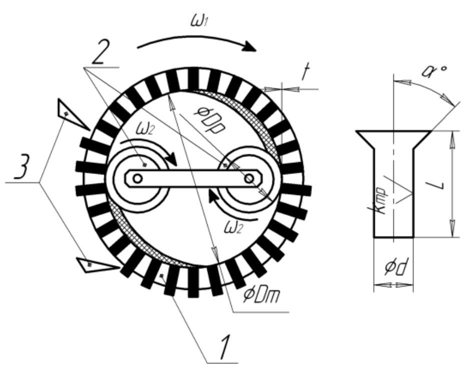

Figure 3. Scheme of work of the granulator unit

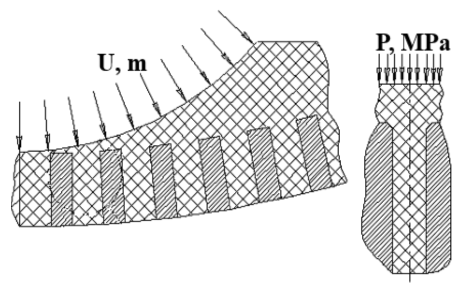

Figure 4. Calculated schemes of the granulation process by extrusion.

The key technologic operation takes place within granulator pressing unit, i.e., the operation of granulating the raw materials through matrix holes by extrusion. Figure 4 shows the calculations of the granulation process.

The first calculated scheme in Figure 4 (a) presents the part of granulator matrix with holes, where raw material is confined in the upper part by a pressing roller. Scheme takes into account both the granulator matrix geometry (its diameter, and distance between holes and pressing roller diameter as well as air gap between matrix and roller.

The second calculated scheme in Figure 4 (b) shows granulator matrix channel. The scheme takes into account geometry size of the channel, namely, the length, the diameter and the bevel size.

3. Results and Discussion

The given study we are concerned with the processes which go on at the very time of extrusion, that is, we are especially interested in the behavior of the raw material in the holes of granulator matrix.

The question arises as to what hole we should examine at a certain time and where the process of pressing flows most intensively.

In order to find such a hole the necessary calculations were conducted (calculated scheme figure 4.a), which resulted in the diagram creation, that allows defining the specific size of the hole. The diagrams of movement allocation at X and Y axes show that maximal movement we can notice in hole 3 and hole 4, Figure 5, correspondingly.

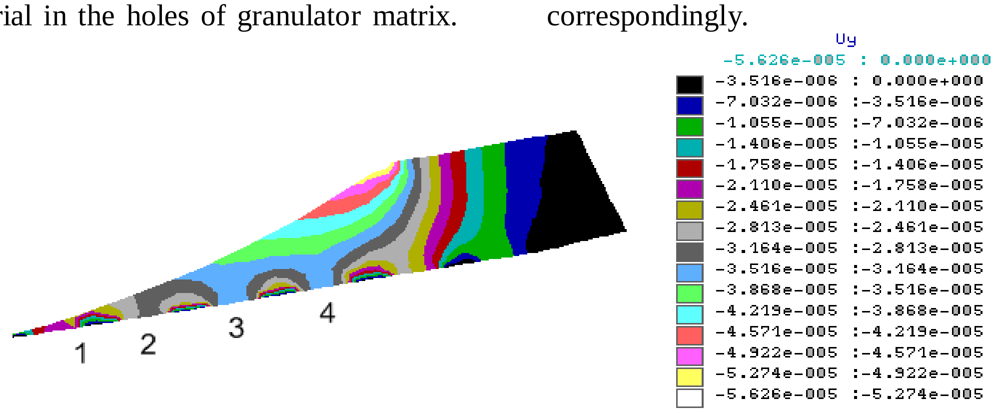

Figure 5. Diagram of movement allocation at Y axis.

The diagram of pressure gives possibility to define the values of pressure which act in the particular area. Data obtained after calculation the first model were used to construct the following model (calculated scheme Figure 4.b).

In this case, we are interested in the behavior of raw material in the hole of matrix which will result in the opportunity to define dependence between the holes geometry and raw material behavior under granulation process.

Figure 6 shows the example of the obtained results after numeric modeling of the extrusion process of the raw material through matrix.

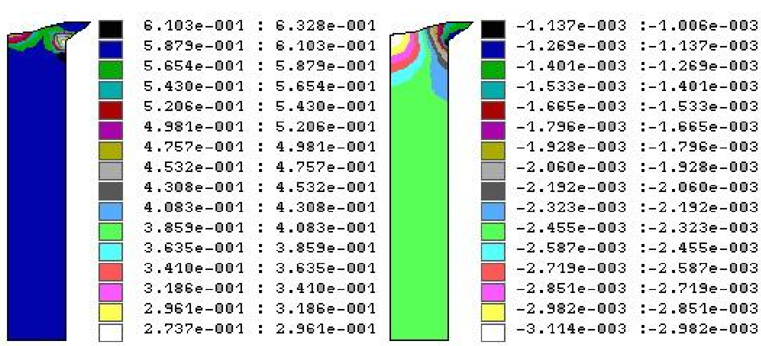

Figure 6. Allocation of a) movements and b) porosity in the bulk volume of dispersed material.

Based on the obtained data, taken as an example, the graphs of pellet density dependence on main design and technological parameters of the granulator unit under different values of pressure were constructed

So, the figure 7 shows the dependences for sunflower husk.

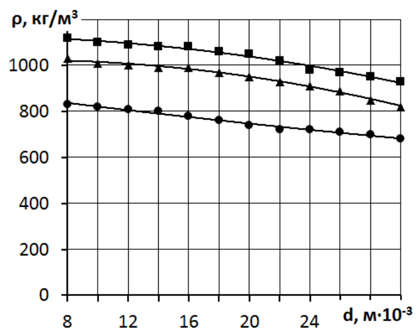

Figure 7.a. Density dependence of ρ pellets on *d* hole diameter
● - 50MPa, ■ - 100MPa, ▲ - 150Mpa

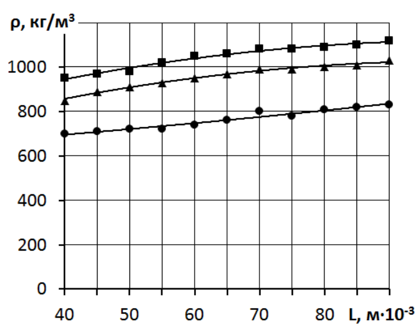

Figure 7.b. Density dependence of ρ pellets on *L* hole matrix length
● - 50MPa, ■ - 100MPa, ▲ - 150MPa

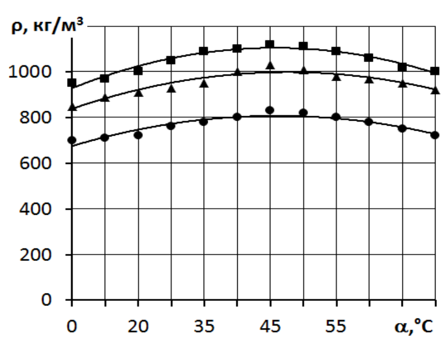

Figure 7.c. Density dependence of ρ pellets on α hole matrix angle
● - 50MPa, ■ - 100MPa, ▲ - 150MPa

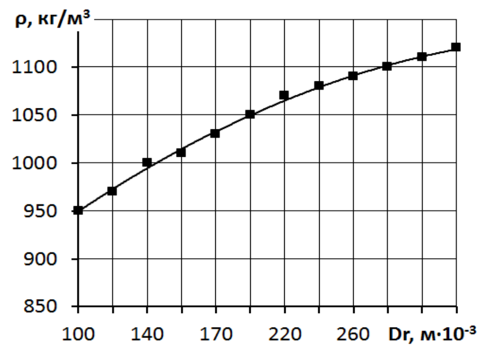

Figure 7.d. Density dependence of ρ pellets on *Dr* roller diameter
● - 50MPa, ■ - 100MPa, ▲ - 150MPa

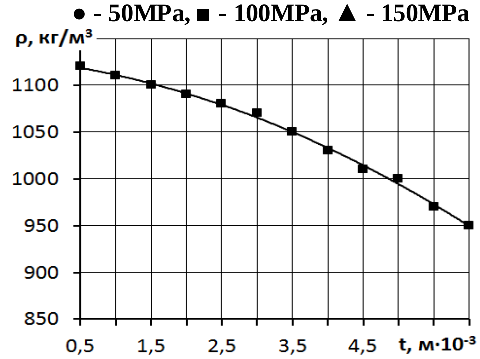

Figure 7.e. Density dependence of ρ pellets on *t* air gap size between roller and matrix

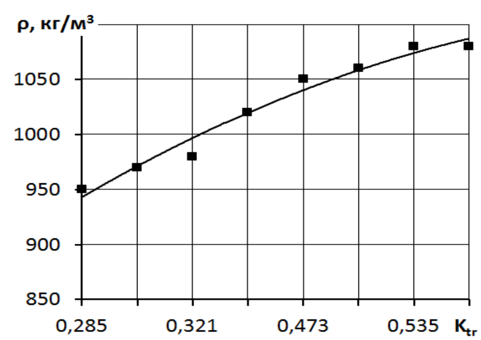

Figure 7.f. Density dependence of ρ pellets on friction coefficient between DM and matrix

4. Conclusion

So, the developed mathematical model gives possibility to define interdependences between main design and technological parameters of pressing granulator taking into account type of raw materials. It is advisable to use the gained results as recommendations in designing granulating equipment.

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