Fluid Mechanics: Open Access

Design Parameters of a Screw Extruder for Biofuel Production

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Abstract

In this paper, the methods of non-destructive testing of industrial objects, as well as various types of this method, such as magnetic, electric, which are used to create new laboratory work in the educational process. The development of non-destructive testing in Saint-Petersburg State University of aerospace instrumentation (SUAI) is reflected in the appearance of new terms that are used in practice, scientific papers and technical descriptions. Non-destructive control increasingly contacts with adjacent areas involved in assessing the actual technical condition of the facilities, determining the possibility of their further operation and the terms of safe operation (resource problem).

Keywords: Organic wastes; Extruder; Molding die block; Pelletising; Modeling; Molding parameters

Introduction

An extruder working element is a combination of screw and die block that define the shape, size and quality of finished products (fuel pellets). The die block comprises draw dies that define the extruder performance and the quality of pelletised biofuel. The selection and justification of dimensions, section shapes and the number of draw dies in the die block allow producing pellets with specific quality characteristics.

The pelletising process is controlled through the following parameters: current, screw speed, feed humidity, die block and draw die shapes, biomass composition, and the number of pre-treatments [1].

The biomass pelletising process is accompanied by sufficiently high pressure that is required to destruct residual fibers and compact the processed mass [2]. Along with positive contribution of pressure into the quality of fuel produced, power necessary for molding is substantially increased [3].

Material and Study Methods

The studies of the extruder molding process were carried out based on peats of various humidity, and to study the power consumption of the unit in processing, MN-2 screw extruder was selected (Figure 1).

Processing power output 1.3 kW, throughput 20 kg/h. Components: 1 - pusher; 2 - loading bowl; 3 - screw channels; 4 - housing; 5 - drive housing cover; 6 - driver housing; 7 - gear pairs; 8 - engine, 9 - screw

Figure 1: MN-2 screw extruder.

pin; 10 - draw ring, draw die; 11 - screw; 12 - bushings; 13 - screw shank; 14 - draw die.

The MN-2 screw extruder engine is connected to a Huyndai N100 frequency converter to change the screw speed and monitor any changes in current, voltage and rpm depending on various humidity of the peat to be processed. A test bed is represented in Figure 2.

1 -balance (0.01 g); 2 -computer with N100 software package installed to analyze the frequency converter operation; 3 -muffle furnace and microwave oven to dry individual pellets; 4 -fuel pellet produced; 5 -set of draw dies; 6 -extruder based on 722-2M meat grinder; 7 -lever to feed peat into the extruder's chamber; 8 -HyundaiN100 frequency converter; 9 -AnD electronic moisture tester; 10 -fluidized bed drier.

Accroding to the works of Chistyy, laboratory and full scale tests of screw extruders revealed that, in standard condition (humidity of 50%), the quality of fuel pellets depends on the ratio of the draw die

Figure 2: Test bed for studying the cold extrusion process.

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length to its diameter and may significantly vary depending on the shape of holes where raw materials are fed [4].

In case a draw die shows an insufficient capability of relaxation, after molding, it may produce pellets with uneven surfaces. Non-relaxed materials coming out of the draw die rapidly gain the required relaxation peak followed by the diameter being quickly increased, which creates a central crack that substantially grows in size when drying and when the moisture goes out of pores, so that all bonds between particles are broken and the pellets tendency to crumble increases (Figure 3).

During the experiment, a frequency converter allows monitoring the engine speed and, consequently, the screw speed. Experiments have been carried out intended to reveal the maximum extruder throughput when crushing peat with 75% humidity in case of no processing, single or double processing. For this purpose, 180 g of peat were placed into a preliminary cleaned extruder chamber to be processed for 15 seconds. According to one of the suggestions, the screw sometimes fails to capture the sufficient amount of materials with its vanes at various speeds when feeding the peat into the screw chamber.

Study Results

In case of high biomass humidity, the dry substance concentration in a volume unit is low, and interaction forces between particles are not too high in this case. Insufficient resistance to setting from the framework of plant residues and the strain in the drying surface layer may cause cracking [5,6]. When the initial humidity is reduced, the framework of plant residues also shows significant resistance to setting, but as the peat dries out, the increased number of particle contacts promotes more intensive development of attraction forces between them and better compaction (Table 1) [7].

During processing, a high amount of materials sticks to the guiding channels of the housing and the screw surface. The material is intensively processed in the thin wall-adjacent layer, and this becomes the primary cause of the sticking of the material to the channel walls and reduced throughput (Figure 4).
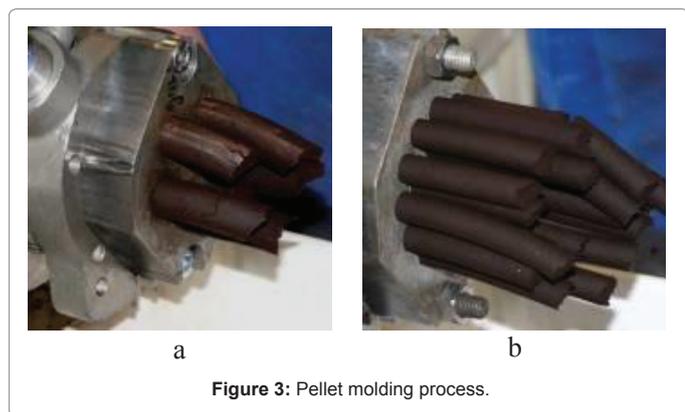
Figure 3: Pellet molding process.

The shaft rpm was adjusted by a frequency converter to make the screw decelerate slower. As is well-known, the period of time when the pressure affects the biomass varies within fractions of a second in molding mechanisms of the extruder [8].

Studying the energy dependency of peat mechanical processing is of greatest importance for peat brick production. The current measurement results in the production of peat of various humidity and degree of fineness are given in Table 2.

The operation analysis of screw die blocks of various designs was done by creating a 3D simulation model of operation in the ParaView software environment. For simulation purposes, twelve die block sizes were modeled whose surface was divided by using the finite element method. The area where differential equations are solved is divided into the finite number of subregions (elements). A type of the approximation function is randomly selected in each element. In the simplest case, this is a first degree polynominal. The approximation function equals zero beyond its element. The values of the function at the borders of elements (in nodes) for the solution of tasks are unknown in advance [9]. The coefficients of approximation functions are usually sought based on the equality of adjacent function values at the borders between elements (in nodes). These coefficients are then expressed through the values of functions in the nodes of the elements. The system of linear algebraic equations is produced. The number of equations equals the number of unknown values in nodes where the solutions of the initial system are sought and is directly proportional to the number of elements and limited by the PC capabilities only. Since each element is connected to a limited umber of adjacent ones,
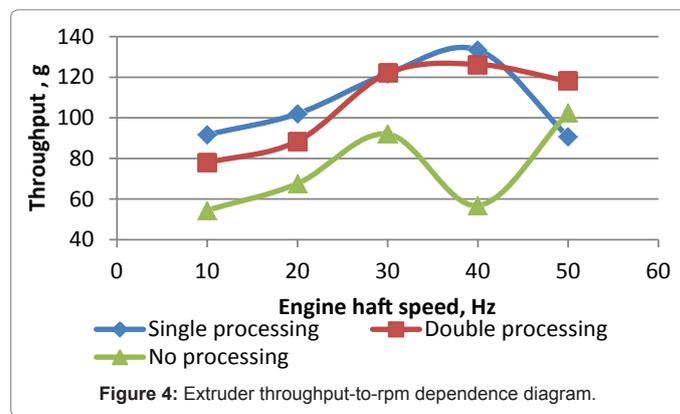
Figure 4: Extruder throughput-to-rpm dependence diagram.

No.	Humidity, %	Current, A	
		Single processing	Double processing
1	57	5.7	6.3
2	64	1.9	2.3
3	72	1.7	2.4

Table 2: Current changes depending on peat processing.

No.	Speed, rpm	Amount produced from biomass with no pre-relaxation, g		Amount produced from biomass after single pre-relaxation, g		Amount produced from biomass after double pre-relaxation, g	
		15 sec	60 min	15 sec	60 min	15 sec	60 min
1	10	54.5	13,080	91.7	22,008	77.9	18,696
2	20	67.6	16,224	102	24,480	88.5	21,240
3	30	92	22,080	121.7	29,208	122	29,280
4	40	56.8	13,632	133.4	32,016	126.3	30,312
5	50	102.4	24,576	90.6	21,744	118	28,320

Table 1: Throughput changes depending on the screw rpm.

the system of linear algebraic equations is sparsely populated, which substantially simplifies its solution. 3D models of the extruder die block are given in Figures 5-7.

When calculating the modeling forces, several force parameters affecting the screw could be analyzed (Figure 7). The results of 3D modeling of die block are summarized in Table 3.

The screw extruder die block No. 5 shows the most sustainable parameters, which corresponds to optimal values between the minimal force at the screw shaft and the maximum mass flow velocity.

Figure 5: Types of 3D modules of extruder die block with d1/d2=1:3. Modeled inclination angles: 1 – 15°; 2 – 17.5°; 3 – 20°; 4 – 25°; 5 – 30°; 6 – 0°.

Figure 6: Types of 3D modules of extruder die block with d1/d2=1:4.5. Modeled angles and radii: 1 – 17.5°; 2 – 30°; 3 – 60°; 4 – 0°; 5 – 60°; 6 – 60°.
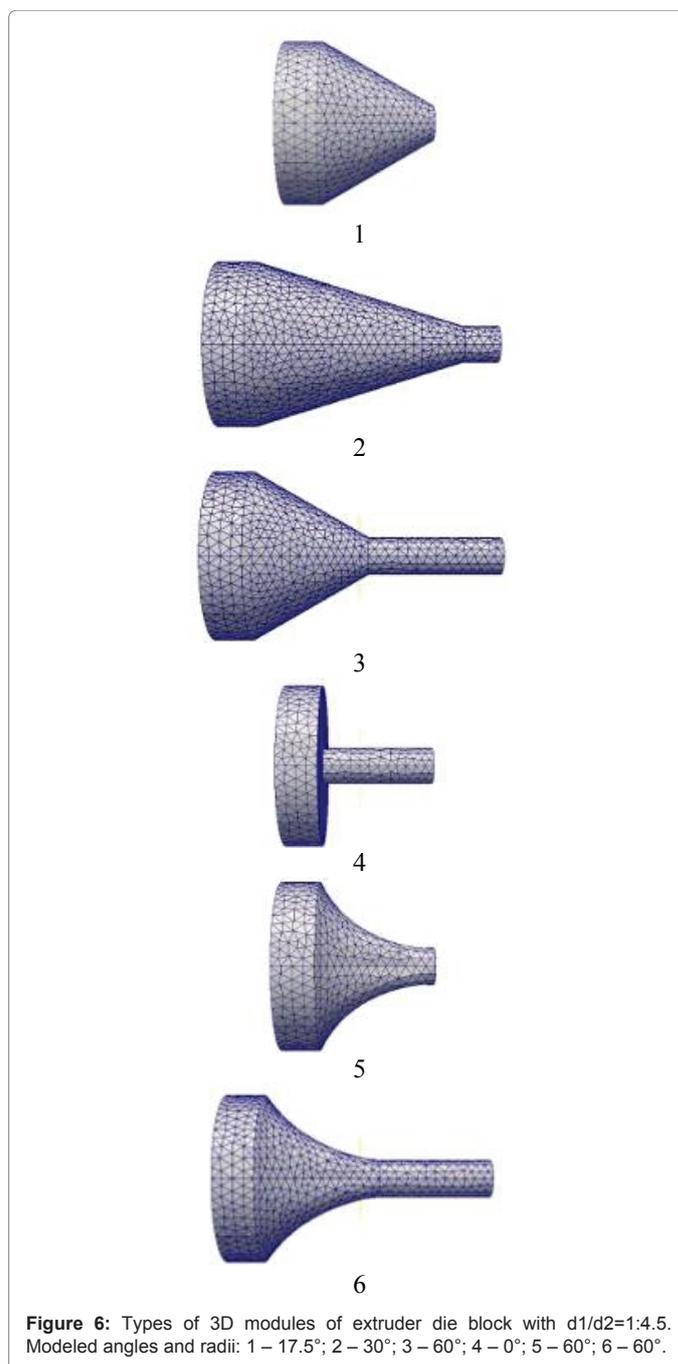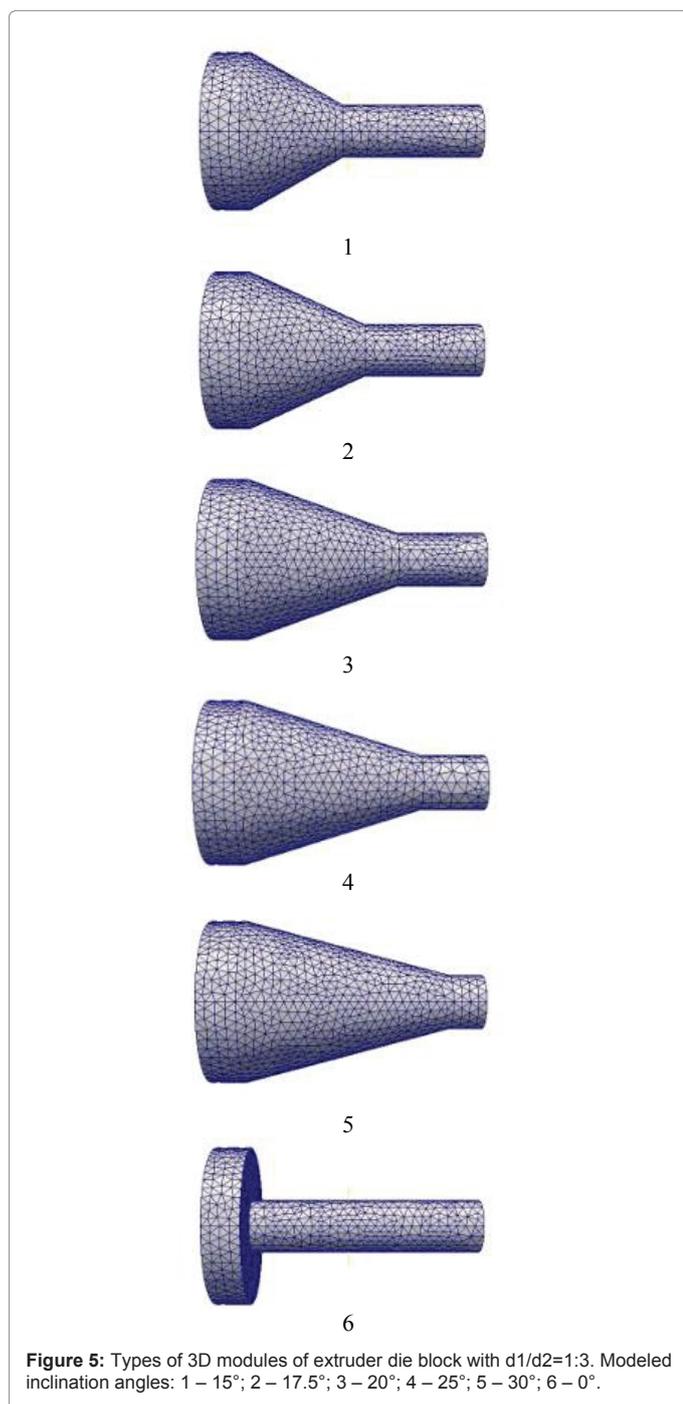
Discussion of Results

Based on the theoretical studies, experimental molding was carried out, and limit values of screw extruder operation were determined. The experimental humidity of the blend molded was determined: 70-72%. The humidity of the molded blend of 50-60% causes stopper plugs to be formed in the draw die, which causes the extruder to stop (Figure 8).

The humidity of the molded blend of 75% causes shapeless fuel pellets to be formed with insufficient strength characteristics. To select sustainable parameters of the molding process, we assume the data summarized in Table 4.
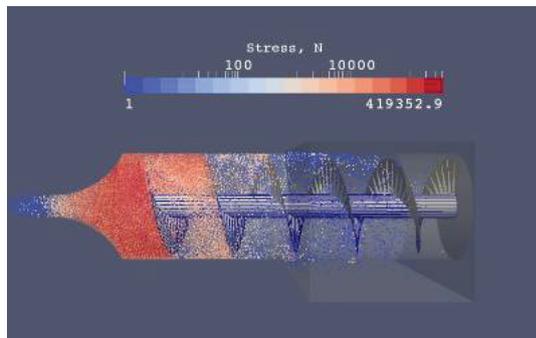
Figure 7: Exemplary data analysis in software.

No.	Head shape	d1/d2	L, mm	v, m/s	Qnorm, kPa	Qtang, kPa
1	0°	1/4.5	70	6.553	589	62
2	17.5°	1/4.5	130	6.56	559	60.3
3	30°	1/4.5	130	6.7	583	75.7
4	60°	1/4.5	70	6.7	424	37.9
5	**R60**	**1/4.5**	**70**	**6.4**	**419.35**	**75.7**
6	R60	1/4.5	100	7.11	746.3	84.6
7	0°	1/3	130	7.1	773	93.1
8	15°	1/3	130	5.94	421.39	42.44
9	17.5°	1/3	130	6.36	501.99	55.716
10	20°	1/3	130	6.36	501.9	55.716
11	25°	1/3	130	6.51	501.9	55.71
12	30°	1/3	130	6.57	571.8	66.217

Table 3: 3D modeling results.

No.	Parameter	Indicator
1	Current	1.7 A
2	Shaft speed	40 rpm
s3	Die block shape	R60, d1/d2=1/4.5
4	Humidity	70-72%
5	No. of pre-processings	single

Table 4: Selecting sustainable parameters of the molding process.

Figure 8: Stopper plug extracted from the draw die.

Narrowing the draw die cylindrical section along the catenary line allows significantly improving the quality of the molded mass as compared to a right narrowing cone and the draw die right angle. The following circumstances can serve as justification of narrowing the draw die along the catenary line: on the one hand, pressure is exponentially reduced along the channel length due to energy losses for mass deformation and friction against the draw die wall, and on the other hand, the mass resistance to deformation grows exponentially as the material moves in the draw die. The total of these dependencies yields a hyperbolic cosine -a catenary line. Therefore, taking these processes into account simultaneously creates better conditions for relaxation processes [10-15].

Conclusion

By the example of structural and mechanical characteristics of the peat paste, the studies showed that it obeys the Bingham plastic model during deformation. Based on the experiments, the draw die design of the press matrix has been justified. The draw die made of a catenary line ensures the friction forces to be reduced between the peat mass and the draw die internal surface comprised of molding and calibrating parts.

It has been established that the primary functional characteristics of a high-quality screw extruder include as follows: precision of the geometric characteristics of the shape (deviations of dimensions, deviations from a straight shape), molding speed, readiness coefficient (maximum period between cleaning operations, cleaning and maintenance convenience, time required to mount and dismount the tool, convenient setting of various operating modes), and the durability and reparability of the tool.

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