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Effect of Humidity of Poly-Cereal Flour Mixture and Screw Rotation Rate on Efficiency of Extrusion Process

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ABSTRACT

The food industry is an important constituent of a country's economy, which provides the population with food. The development of the food industry and the supply of food products to the entire population requires improving food-manufacturing technologies, such as the process for production of extruded poly-cereal food products using high-temperature extrusion. Experimental production of extruded poly-cereal food products of high degree of preparation was carried out using an industrial extruder equipped with an automatic control board. Following the results of study of extrusion of poly-cereal flour mixture on commercial twin-screw extruder dependencies of parameters, defining efficiency of the process, on variable value of rotation rate of the extruder screw, n (min-1) and humidity of extruded poly-cereal flour mixture, W (%). Received dependencies adequately describe poly-cereal mixture extrusion process management. The results of the research have practical significance when improving the scheme of manufacturing of poly-cereal products of high degree of preparation.

KEYWORDS
Poly-cereal mixtures, extrusion technology, twin screw extruder, humidity, rotation rate

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Introduction

The most important task of the food industry of the Republic of Kazakhstan is to develop scientific, theoretical and practical basis to obtain new forms of food products, as a brand new area for expansion of the line of grain-based food products (Giles, 2005; Ospanov et al., 2014; Rudenko et al., 2016). Implementation of such area prospective for Kazakhstan's economy is possible by means of development and improvement of process for production of extruded poly-cereal food products using high-temperature extrusion (Ospanov, Muslimov & Dzhumabekova, 2014; Steele et al., 2015).

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It should be noted, that the major component of the raw material, used in different extrusion technologies, is starch, the high-molecular natural polymer, which occurs in large amounts in almost all cereals and their derivative products, and in smaller amounts – in grain legume crops with high content of protein (Chen & Rosenthal, 2015; Bouvier & Campanella, 2014; Shahidi, Ho & Van Chuyen, 2013). While, according to many scientists, extrusion processing of starch-containing raw materials, is an eco-friendly, resource-efficient and universal process, which provides an opportunity to obtain easy-digestible, thermally sterilized food products with improved taste properties (Ostrikov, Vasilenko & Sokolov, 2009; Burtsev, Gritskih & Kasyanov, 2004; Magomedov & Brekhov, 2003).

Within the last 5-7 years the market of extruded products transitioned from extensive to intensive development, i.e. the growth of the market is maintained not by growth of production of one certain type of product, but by development of new types of finished products (Ostrikov, Vasilenko & Sokolov, 2009; Stenvik, 2014; Kobussen et al., 2015).

Therefore, one of the priority areas in improving methods and technologies for production of brand-new grain-based food products is to improve the degree of preparation and to extent line by extruding poly-cereal flour mixture, which, in turn, is a relevant and appropriate task.

The results given in article are received during performance of research works on subjects: "Developing the technology of production of highly prepared products from domestic poly-cereal feedstock" (# the state registration 0112PK01528) and "Development of technology of production of extruded poly-cereal convenience foods with fruit and berry, as well as with meat and dairy filling" (# the state registration 0115PK00719) on grant financing of scientific researches of Committee of science of the Ministry of Education and Science of RK.

Aim of the Study

This research aims to investigate the process of production of extruded poly-cereal food products of high degree of preparation

Research questions

How do the operating characteristics of the extruder change under changes in the rotation speed of the screw?

Method

Experimental manufacture of the preproduction lot of extruded poly-cereal food products of high degree of preparation was performed on a commercial extruder, equipped with automatic control board, cooling chamber, receiving bin with dosing machines, twin-screw pressing unit (extrusion zone) and the device for release of finished products. Extruder design implements modern engineering solutions, designed to improve product manufacturing process.

The extruder is equipped with 90 kW electric drive and has a capacity of 450 kg/h. The key feature of the plant design is an automated system for setting and control of thermal control parameters, which includes *pit*-regulators, which ensure stability of thermal conditions in extrusion zones. Specifically designed self-cleaning screws prevents ingress of carcinogens and solid particles to finished products, which helps to avoid dismantling and cleaning extrusion zone of the plant upon completion of work.

Advantages of the experimental twin-screw extruder are (Gaspar & de Góes-Favoni, 2015; Keller et al., 2012; Kaur et al., 2012):

– simple design and ease of application of the plant;
– automated heating and cooling control system of the technology zone;
– low noise level;
– adjustable rotation rate of extruder motors, cutting device and dosing machines using frequency control drive;
– extruder is equipped with 1 m^3 dry mixture collecting bin, installed above dosing mechanism for dry components;
– extruder is equipped with conditioner;
– plant is equipped with a system for registration and storage of parameters of technology process with real-time data output.

Methods for manufacture of preproduction lot of extruded products of high degree of preparation consists in the following. We have defined optimal operation mode of the extruder using automated system for setting and control of thermal control parameters via control board. Pre-prepared poly-cereal mixtures (prepared according to science-based formula) were loaded into receiving device of the twin-screw extruder with dosing mechanism. Next we extruded poly-cereal flour mixture at fixed rates of rotation of the working member and humidity of mixture.

In the course of extrusion the poly-cereal mixture passed through pressing unit (extrusion zone) and at the output from extrusion zone through outlet assembly we obtained finished products in the form of extrudates. Further the finished products were cooled on the frame with woven-wire-cloth sieve coating in order to avoid sticking of the products obtained. Thereafter obtained products were transferred to the finished products reservoir.

During the experimental researches the efficiency of operation of the twin-screw extruder was controlled by registration of the following variable parameters:

- pressure, built in pre-matrix zone (*P*, MPa);
- temperature of the finished products at the output from the working zone (*t*, °C);
- extruder output (*Q*, kg/h);
- power consumed by the electric drive during extrusion process (*N*, kW).

Data, Analysis, and Results

The findings of the experimental researches were entered into *Microsoft Excel* tables. Based on data obtained we constructed graphs of dependency of pressure, built in the pre-matrix zone (*P*, MPa), temperature of finished products at the output from the working zone (*t*, °C), extruder output (*Q*, kg/h) and power consumption of the electric drive during extrusion process (*N*, kW) on variable values of rotation rates of the extruder screw *n*, (min^{-1}) and humidity of the extruded poly-cereal mixture, *W* (%).

Figure 1 shows 3D model, which describes dependency of pressure in the pre-matrix zone of the twin-screw extruder on humidity of poly-cereal flour mixture and rotation rate of the working member of the experimental plant.

Analysis of behavior of the 3D surface demonstrated, that increase in rate of rotation of the working member n from 80 to 250 min^{-1} leads to increase in values of pressure in the pre-matrix zone. At the same time humidity of the processed poly-cereal flour mixture reduces P values during extrusion. Thus, for instance, at the 12 % humidity of a poly-cereal flour mixture and rotation rate of the screw 80 min^{-1} P value made up 11.0 MPa. At $W = 13.5$ % and $n = 80$ min^{-1} P value made up 11.7 MPa. Increase in humidity up to 15 % led to increase in P values up to 12.0 MPa. Further increase in humidity up to 18% reduced pressure values down to 11.45 MPa.

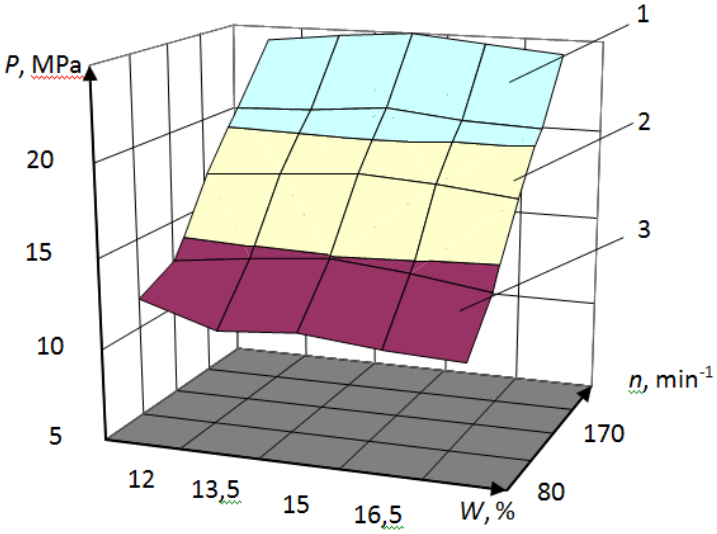

Figure 1. Dependence of change in pressure in the pre-matrix zone of the extruder (P, MPa) on humidity (W, %) and the rotation rate of the working member (n, min^{-1}). Area, characterized by pressure in the pre-matrix zone: 1 – 20-25 MPa; 2 – 15-20 MPa; 3 – 10-15 MPa.

$$P = 220.7012 - 26.6439w - 0.1053n + 0.0018wn + 0.8829w^2 + 0.0004n^2 \quad (1)$$

Figure 2 shows the 3D model, which describes dependency of extrudate temperature at the output of the working zone of the plant on variable value of humidity of poly-cereal flour mixture and rotation rate of the working member of the experimental plant.

Analysis of behavior of the three-dimensional surface showed, that increase in the rotation rate of the working member (screw) n from 80 to 250 min^{-1} led to increase in values of extrudate temperature at the output of the working zone of the plant (t, °C). At the same time the humidity of the processed poly-cereal flour mixture changes t values during the extrusion process. Thus, for instance, at 12 % humidity of the poly-cereal flour mixture and the rotation rate of the screw = 80 min^{-1}, t value made up 124.5 °C. At $W = 13.5$ % and $n = 80$ min$^{-1,}$ t value made up 126.8 °C. Increase in humidity up to 15 % led to increase in P values up to 130°C. Further increase in humidity up to 18 % decreased extrudate temperature values at the output of the working zone of the plant.

Similar dependences have been obtained when changing values of rotation rate of the working member from 120 to 250 min^{-1}. Maximum values of t = 250 °C occurred when rotating the working body at n = 250 min^{-1}.

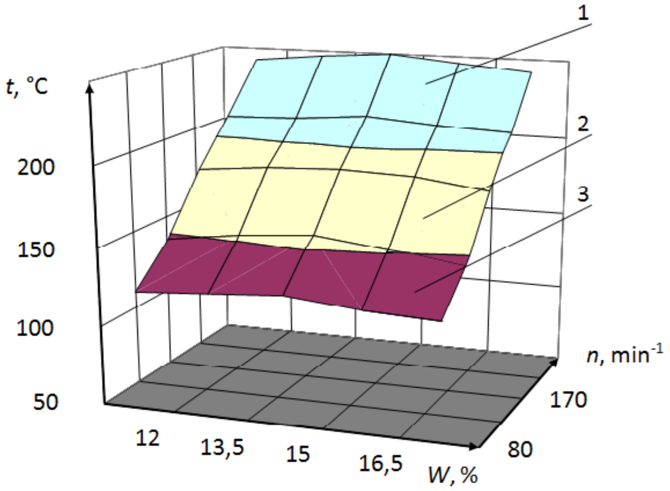

Figure 2. Dependence of change in temperature of the extrudate at the output of the working zone of the plant (t, °C) on humidity (W, %) and rotation rate of the working member (n, min^{-1}). Area, characterized by extrudate temperature: 1 – 200-250°C; 2 – 150-200 °C; 3 – 100-150 °C

$$t = 153.8504 + 27.9326w + 0.9686n - 0.0007wn - 0.9712w^2 - 0.0005n^2 \quad (2)$$

Figure 3 shows a 3D model, which describes dependency of twin-screw extruder output on variable values of humidity of poly-cereal flour mixture and the rotation rate of the working member of the experimental plant.

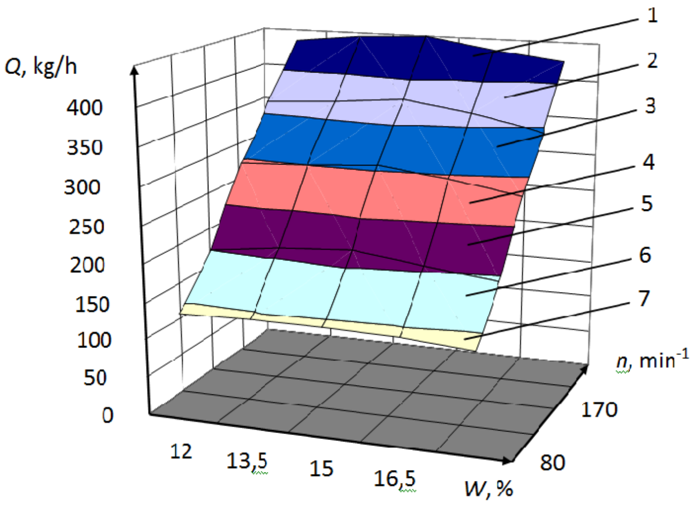

Figure 3. Dependence of changing extruder output (Q, kg/h) on humidity (W, %) and the rotation rate of the working member (n, min^{-1}). Area, characterized by extruder output:1 – 400-450 kg/h; 2 – 350-400 kg/h; 3 – 300-350 kg/h; 4 – 250-300 kg/h; 5 – 200-250 kg/h; 6 – 150-200 kg/h; 7 – 100-150 kg/h.

$$Q = 95.8189 - 36.1631w + 4.7981n + 0wn + 0.9027w^2 - 0.0088n^2 \quad (3)$$

Analysis of behavior of three-dimensional surface showed, that increase in rotation rate of the working member (screw) n from 80 to 250 min^{-1} led to increase in twin-screw extruder output (Q, kg/h). At the same time humidity of the processed poly-cereal flour mixture changes Q values during the extrusion process. Thus, for instance, at 12 % humidity of the poly-cereal flour mixture and rotation rate of the screw = 80 min^{-1}, Q value made up 140 kg/h. At W = 13.5 % and n = 80 min^{-1} Q value had increased and made up 142 kg/h. Increase in humidity up to 15% led to increase in Q values up to 144 kg/h. Further increase in humidity up to 18 % at n = 80 min^{-1} reduced plant output values down to 135 kg/h. Similar dependences have been obtained when changing values of the rotation rate of the working member from 120 to 250 min^{-1}.

At the same time the maximum Q value made up 450 kg/h at the rotation rate of the working member n = 250 min^{-1} and 15% humidity of the poly-cereal flour mixture.

Figure 4 shows 3D model, which describes dependence of power, consumed by the electric drive of the extruder (N, kW) on variable humidity values of poly-cereal flour mixture and rotation rate of the working body of the experimental plant.

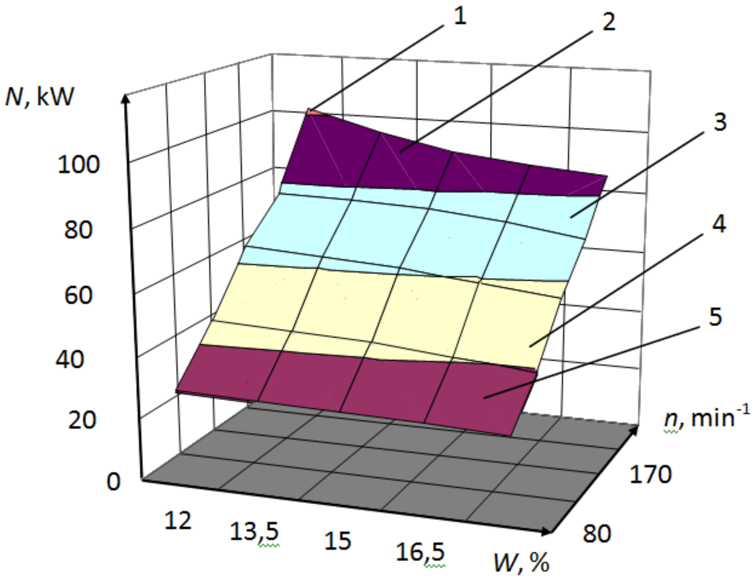

Figure 4. Dependence of power consumed by the electric drive of the extruder (N, kW) on humidity (W, %) and rotation rate of the working member (n, min^{-1}). Area, characterized by electric power consumption: 1 – 100-120 kW; 2 – 80-100 kW; 3 – 60-80 kW; 4 – 40-60 kW; 5 – 20-40 kW.

$$N = 246.0047 + 32.4651w + 05029n - 0.0018wn - 1.1293w^2 - 0.0001n^2 \quad (4)$$

Discussion and Conclusion

Analysis of behavior of the three-dimensional surface showed, that increase in rotation rate of the working member (screw) n from 80 to 250 min^{-1} leads to increase in power consumption by electric drive of the extruder (N, kW). At the same time humidity of the processed poly-cereal flour mixture reduces N values during extrusion process (Ospanov & Timurbekova, 2016).

Thus, for instance, at 12% humidity of a poly-cereal flour mixture and rotation rate of the screw = 80 min^{-1}, N value made up 29.5 kW. At W = 13.5 % and n = 80 min^{-1}, N value made up 29.0 kW. Increase in humidity up to 15 % led to reduction of N values down to 28.8 kW. Further increase in humidity up to 18% at n = 80 min^{-1} reduced power consumption by the electric drive of the plant down to 27.0 kW. Similar dependences have been obtained when changing values of the rotation rate of the working member from 120 up to 250 min^{-1}. At n = 120 min^{-1} and W = 12 % power consumption of the electric drive of the plant made up 45.5 kW. Increase in n values up to 170 min^{-1} led to increase in N values up to 64.5 kW. Further increase in n values up to 250 min^{-1} led to increase in N values up to 102 kW. Maximum power consumption by the electric drive made up 102.0 kW at the rotation rate of the working member n = 250 min^{-1} and 12 % humidity of the processed material.

Analysis of the obtained three-dimensional surfaces showed, that operational characteristics of the extruder for all values of rotation rates of the screw are of the same form, i.e. at first the pressure in the pre-matrix zone of the extruder grows alongside with increase of output, and then after a certain Q value it decreases. It is clear that in the mode of the completely closed output at $Q = 0$, the pressure in the pre-matrix zone continuously rises, while in the mode of the open output at $Q = Q_{max}$ it continuously drops. As for a real extrusion process, with a growth of the output, the pressure of the products reaches a certain value, which is the highest for such operating conditions of the extruder, and then consistently drops. Maximum at the curves deflects towards increase of the output.

Implications and Recommendations

Dependences of pressure and temperature of the products in the pre-matrix zone of the extruder on variable parameters of the extrusion process helps to forecast their changes within the investigated range of factor values with an adequate accuracy. Analysis thereof results in the conclusion that factors considered have dominant effect on temperature and pressure of the food medium: design parameters of the extruder (values of diameter of flow-cross section of the matrix) as well as an initial humidity of the mixture have the greatest impact on the melt pressure of the products; geometrical characteristics of the working member, rotation rate (speed) of the screw and the pressure of the products have the highest impact on the temperature in the pre-matrix zone of the extruder. They help to determine dominant value for each investigated factor (W, n) on kinetic parameters and describe kinetics of the process of extrusion of poly-cereal flour mixture in the course of manufacture of products of high degree preparation with a sufficient approximation. In addition opportunity to combine the composition of poly-cereal flour mixture helps to extent the line of qualitive poly-cereal food products.

Disclosure statement

No potential conflict of interest was reported by the authors.

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