

Studying physical and mechanical characteristics of corn feed

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Abstract. The use of condensed extract in the production of corn feed contributes to the improvement of their nutritional and biological value. The rheological properties of the feed material are of great importance in the mechanical interaction with the working bodies of the machines, in the movement of viscous media along technological conveyors, as well as in the intensification of heat exchange processes. The technique, laboratory equipment and the results of studies of physical and mechanical characteristics of corn feed are presented. The viscosity properties of the corn extract are investigated depending on the temperature. It is shown that when decreasing the temperature, the viscosity of the corn extract increases due to the aggregation of its components, which characterizes the non-Newtonian flow of the extract. The coefficient of external friction of the pulp and extract mixture in the technology of preparing corn feed allows calculating the geometry of the storage tanks and energy costs of the processes. The change in the coefficients of friction of corn feed when interacting with various surfaces, depending on the content of dry substances. The specific heat capacity, thermal conductivity and thermal diffusivity of the extract and corn feed were determined and investigated. It has been revealed that the dependences of the thermo-physical parameters of the extract and corn feed on the solids content are non-linear in nature, monotonously decreasing when increasing the concentration of solids.

1 Introduction

When processing corn for starch, pulp and extract are obtained as bypass. The extract is formed when soaking the corn grain in a sub acid sulfuric acid solution. As a result, proteins, organic acids, carbohydrates, trace elements and partially starch pass into it. For the purpose of further use, corn extract is thickened to dry matter content (DM) of 40..45 %. Due to the high content of nitrogenous substances (up to 45 %) and carbohydrates (up to 25 %) in the dry residue, condensed corn extract is a valuable component in the preparation of the feed mixture for feeding farm animals.

The pulp is a mixture of crushed shells and the endosperm of maize grain, consisting of the coarse (60 %) and small (40 %) fraction. The chemical composition of large and small pulp differs significantly. About half of the dry matter in the large pulp is fiber, and that is starch in the small pulp [1].

Many scientists studied the preparation of starch bypass feeding-stuffs and their physical and mechanical characteristics [1–3].

Currently, it is recommended to produce corn fodder according to the technology developed both in raw and dry forms [4]. The process of preparing feeds from the starch and syrup production bypass is associated with various technological operations with the transportation of the material by the working bodies of machines. The type of interaction of raw materials and its rheological

and surface-contact characteristics are of great importance for the implementation and intensification of technological processes. The friction coefficients allow calculating the shape of the storage bins and having a significant impact on the energy intensity of the technological processes of feed preparation.

Thermo-physical characteristics of the extract and corn feed are necessary when calculating, optimizing and controlling the technological processes of their processing. The knowledge of the thermal characteristics of the pulp and the extract is especially necessary when their drying is accompanied by the change in the temperature of the object over time.

Analysis of the literature revealed that the physical and mechanical properties of the extract and corn feed, such as viscosity, stickiness, friction coefficients, thermal diffusivity, thermal conductivity and heat capacity, are little studied, or their reliable values are absent.

Therefore, the task of investigations was to determine the numerical values of the physical and mechanical and thermo-physical properties of corn extract and its mixture with pulp in feed production.

When determining the numerical values of the physical and mechanical and thermo-physical characteristics of the feed from the mash and corn extract, conventional and private methods were used. In laboratory studies, raw materials and corn feeds were used, produced at public corporation "Ibredkrakhmalpatoka" in Ryazan Region.

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2 Objects and methods

The determination of the corn extract viscosity was carried out according to GOST 9070-75, which presupposes the use of a viscometer to find the kinematic viscosity of materials [5].

To study the kinematic viscosity of the corn extract viscometer VZ-246 was used.

The essence of the method is in measuring the expiration time (in seconds) of a certain volume of the test liquid under the influence of gravity at a constant temperature through a calibrated jet orifice of viscometer VZ-246. To maintain a constant temperature of the liquid, the viscometer was placed in a heating cabinet, which made possible to change the temperature.

Kinematic viscosity was calculated as the product of the viscometer constant at the time of the expiration of the fluid. Dynamic viscosity was the product of the kinematic viscosity of a fluid by its density at equal temperature.

To determine the calibration constant of the jet orifice of the viscometer the flow time of water through it with kinematic viscosity of 100.19 mm²/s at a temperature of 20 °C was measured.

The density of the corn extract was determined by a density gage depending on the dry matter content, varying from 5 to 50 %.

The ability of the material to adhere to the working bodies of the machines is assessed by stickiness, which has been determined by the known method with the help of N.A. Kaczynsky's instrument [1]. The device is an analogue of the scales, one bowl of which is made in the form of a polished steel disk-stamp. Another bowl is designed to install a flask in which water is poured. Before starting the device is balanced.

During the experiment, the metal bowl with corn extract (100 g) was heated in the temperature range from 10 to 90 degrees Celsius, with an interval of 10 °C. Then the polished steel disc was pressed to contact the product. The water from the tank filled the flask until the start of the disc-punch separation from the surface of the extract. The mass of water in the flask was determined by weighing on the scales.

The stickiness of the corn extract was determined as the ratio of the effort of separation of the disk-stamp to its area.

The moisture content of the materials was found using the thermal method according to GOST 13496.3–80 [6]. The bulk weight of corn feed was determined by a liter grain tester PH-1 GOST 7861-74 according to the method described in GOST 28254-89 [7].

The numerical values of the static (at rest) and dynamic (in motion) coefficients of friction of a mixture of corn mash with an extract for various materials of friction were found through the angle of the corresponding friction [8, 9].

The angle of repose of the materials under study was determined on the instrument, which consisted of an inclined plate and a base, articulated together [10]. The inclined plate can change the angle of inclination, which is visually recorded by an angular sector.

When determining the static angle of repose, the inclined plate was covered with a layer of the material under study, 20–25 mm thick and its angle of inclination slowly increased before the beginning of the movement of material particles with fixing the angle of the plate. When finding the dynamic angle of repose, a mixture of corn mash with an extract from the hopper was strewed in an even flow on the upper inclined plate. At the same time, the inclined plate was slowly lowered until the moment when the mixture flow slid along its surface was stopped, fixing the angle of the plate.

The values of static f_s and dynamic f_d coefficients of friction were determined through the tangent of the corresponding angle of repose. The friction coefficients were determined when moving raw materials on carbon structural steel 45 GOST 1050-74 and stainless alloyed steel 08X13 GOST 5632-72. Accepted steel is widely used for the manufacture of processing equipment for the feed production

The angle of repose affects the mixing process at all stages of the process: loading and unloading by gravity from the neck into the mixing area, when the material is seized by the working body of the mixing device and then transported.

The angle of repose of the studied materials was determined according to the method presented in the literature [11, 12]. According to this method, the material went through the hole of the bunker to a flat horizontal plane, while the loose mass formed a cone. The angle of the generatrix of cone and the horizontal plane was determined by the graduated angular sector.

The thermo-physical properties of the condensed corn extract play an important role in heat transfer and are the basis for the thermal calculation of machines. After analyzing the existing methods for determining the thermo-physical characteristics of various materials [13–16], the method of a plate probe was chosen as the most versatile for viscous and free-running studied feed components.

According to the principle proposed by A.F. Chudnovsky [17], we have developed and manufactured an improved device for determining the thermal characteristics of wet dispersed materials. It consists of a heat insulating chamber. A flat probe made of aluminum is placed in the center of it. On the surface of the probe temperature sensor DT-2 is placed. The dimensions of the probe (the length, width and thickness) are respectively 60, 30 and 1.5 mm. The ratio of the length of the chamber to its width is 5:1, and the thickness of the insulating walls is 50 mm. Temperature sensor DT-1 is located at distance l from the probe. The sensing element is placed in the middle of the layer of the test material. To reduce the inertia of the measurement process and improve the accuracy of the experiments, MT-54M micro thermistors designed by V.G. Karmanov and pre-tared on laboratory thermometer TL-2 were used.

In order to control the time-temperature parameters in the test material and the probe, as well as to reduce the complexity of the experiment, an electrical measuring circuit was used, which is shown in Figure 1.

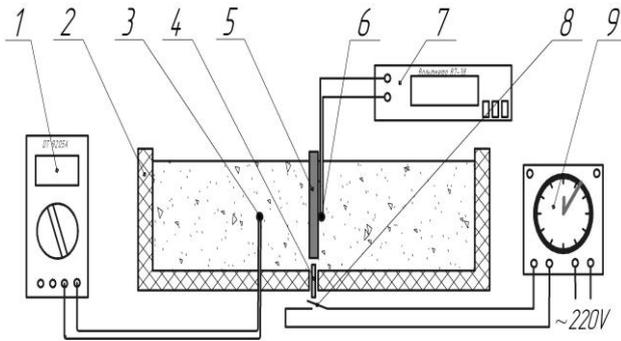


Fig. 1. Functional diagram of the laboratory setup for determining thermo-physical properties: 1 – digital multimeter DT-9205A; 2 – instrument case; 3 – DT-1 temperature sensor of the studied material; 4 – stock; 5 – aluminum probe; 6 – DT-2 probe temperature sensor; 7 – voltmeter V7-38; 8 – stopwatch contact; 9 – SED-1M electric stopwatch

The principle of measuring the thermo-physical properties of the characteristics is based on the application of the method of uniform heating of the material under study in the absence of heat transfer between the sample and the environment [19, 20].

When experimenting, the investigated material was filled into the chamber along the upper edge. Then the probe was heated in a thermostat to a predetermined temperature with an exposure time of 4–5 minutes. The heated probe was inserted into the chamber with the test material, and the stopwatch was automatically activated. The temperature and time parameters were recorded. After the temperature of the heated material passed the maximum and began to decrease, the experiment stopped. During the experiment, the temperature of the test sample was increased according to a linear law by changing the electrical characteristics of the device heater.

The general view of the installation for determining the thermo-physical characteristics of corn extract is shown in Figure 2.

When investigating, the following things were measured: the maximum temperature of the heated sample, the temperature of the probe at the time of its immersion into the material under study and at its maximum temperature, the cycle time. The further determination of the thermo-physical characteristics of the samples was performed indirectly [17, 18].



Fig. 2. The general view of the installation for determining the thermo-physical characteristics: 1 – box with the test material; 2 – probe; 3 – voltmeter V7-38; 4 – DT-9205A digital multimeter; 5 – SED-1M electric stopwatch

The coefficient of thermal diffusivity was determined as the ratio of the squared distance from the probe to the point of measurement of the temperature of the sample under investigation to the double time of the measurement cycle. The distance between the probe and the point of measurement of the temperature of the material in the experiment was taken to be 1.510 – 2 m, which made it possible to carry out the experiment with sufficient accuracy for 10–15 minutes.

The specific heat capacity of the sample was determined, taking into account the amount of heat transferred by the probe to the material during the cycle time and the lag of the change between the upper and lower limit temperatures of the probe, taking into account the volume of the material under study and the constant size of the instrument, which depends on the shape and size of the probe.

The heat conductivity coefficient of the material under study was determined by the product of the specific heat capacity by thermal diffusivity coefficient and sample density.

All experiments to determine the physical and mechanical characteristics of the components of corn feed were carried out with a fivefold repetition. The investigated value was calculated as the arithmetic mean value.

3 Results and discussion

The results of investigations to determine the dependence of kinematic and dynamic viscosity on temperature in the form of graphical dependences are presented in Figure 3.

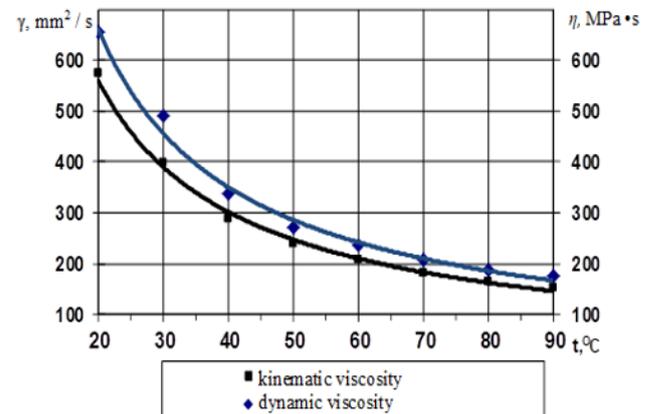


Fig. 3. Graphic dependences of changes in kinematic (γ) and dynamic (η) viscosities of corn extract on its heating temperature (t)

The kinematic and dynamic viscosities of the corn extract decrease with increasing temperature due to a decrease in the molecular adhesion forces of the particles. When the temperature of heating of the condensed corn extract varies from +20 to +90 °C, the kinematic viscosity decreases from 575 to 153 mm²/s and the dynamic viscosity from 645 to 175 MPa·s.

To calculate the heat capacity indices, the density of the corn extract is required at different solids contents.

The graphic dependence of the density of corn extract on the solids content is presented in Figure 4.

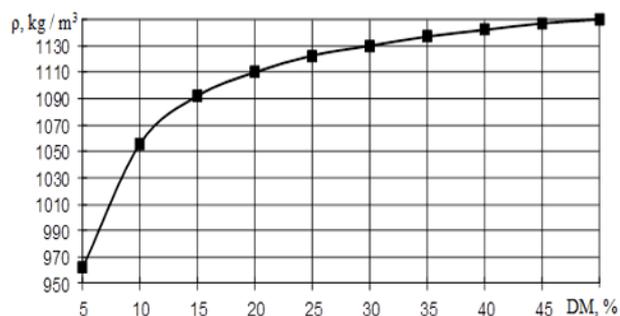


Fig. 4. Graphic dependence of the density (ρ) of corn extract on the dry matter content (DM)

The analysis of the graphical dependence shows that with an increase in the content of dry matter in corn extract, its density increases from 965 to 1150 kg/m³. The condensed extract is a thick brown liquid.

When studying the dependence of the condensed corn extract stickiness (DM = 42 %) on the heating temperature, the values of the punch tearaway force were obtained and the stickiness parameters were calculated.

According to the data obtained, the graphical dependence of stickiness on the heating temperature was built (Figure 5). The value of stickiness decreases from 38 to 11 N/m² when increasing the heating temperature in the range from +20 to +40 °C. With a further temperature increase in the range from 45 to 90 °C, the stickiness changes from 12 to 39 N/m². As can be seen from the graph there is a characteristic extremum. This is due to the fact that initially with an increase in temperature, the viscosity of the corn extracts decreases due to the disaggregation of its components, which leads to a decrease in the stickiness of the extract. Then, at temperatures above 50°, the proteins are denatured gradually due to the acidic environment, and they are precipitated, which causes the stickiness of the condensed extract to increase [21].

When studying physical and mechanical and thermo-physical properties of corn feed, a mixture of pulp and condensed corn extract with preliminary neutralization of its acidity was used in the ratio of 6.4:1. The feed was produced according to the technology developed by us [22–24] at the corn processing plant, public corporation "Ibredkrakhmalpatoka" in Shilovsky District of Ryazan Region. The corn feed can either wet or dry mix. The composition of corn feed is presented in the Table 1.

Table 1. Chemical composition of corn feed

Item number	Name, units	Regulations	Results
1	Moisture content, %	GOST 13496.3	6.6 ± 0.4
2	Mass fraction of crude protein,	GOST 13496.4	22.23 ± 0.39
3	Mass fraction of crude fat,	GOST 13496.15	2.34 ± 0.49
4	Mass fraction of crude fiber,	GOST P 52839	8.5 ± 1.1
5	Mass fraction of ash,	GOST 26226	6.4 ± 0.3
6	Mass fraction of calcium,	GOST 26570	0.1 ± 0.04
7	Mass fraction of phosphorus,	GOST 26657	0.8 ± 0.14
8	Mass fraction of sugar,	GOST R 51637	2.82 ± 0.78
9	Mass fraction of starch,		8.8 ± 1.4
10	Protein digestibility with pepsin and pancreatin	3 hours	80.9
11		24 hours	83.0
12	Mass fraction of potassium,	GOST R 53887	1.75 ± 0.18
13	Mass fraction of sodium,		0.40 ± 0.04
14	Mass fraction of chlorides,	GOST R 52181	0.30 ± 0.06
15	Mass fraction of total iron, mg/kg	GOST R 51637	169 ± 32
16	Mass fraction of copper, mg/kg		7.8 ± 1.6
17	Mass fraction of zinc, mg/kg		100 ± 20
18	Mass fraction of manganese, mg/kg		22.3 ± 4.5
19	Mass fraction of asparagine, %	GOST 13496.21	1.16 ± 0.12
20	Mass fraction of threonine, %		0.81 ± 0.08
21	Mass fraction of serine, %		0.89 ± 0.09
22	Mass fraction of glutamine, %		3.21 ± 0.32
23	Mass fraction of proline, %		2.03 ± 0.20
24	Mass fraction of glycine, %		0.98 ± 0.10
25	Mass fraction of alanine, %		1.67 ± 0.17
26	Mass fraction of valine, %		1.08 ± 0.11
27	Mass fraction of isoleucine, %		0.59 ± 0.06
28	Mass fraction of leucine, %		1.83 ± 0.18
29	Mass fraction of tyrosine, %	GOST 13496.22	0.47 ± 0.05
30	Mass fraction of phenylalanine, %		0.92 ± 0.09
31	Mass fraction of histidine, %		0.71 ± 0.07
32	Mass fraction of lysine, %		0.86 ± 0.09
33	Mass fraction of arginine, %		0.84 ± 0.08
34	Mass fraction of cystine, %		0.46 ± 0.05
35	Mass fraction of methionine, %		0.37 ± 0.04
36	Mass fraction of vitamin E, mg / kg		GOST R 52147

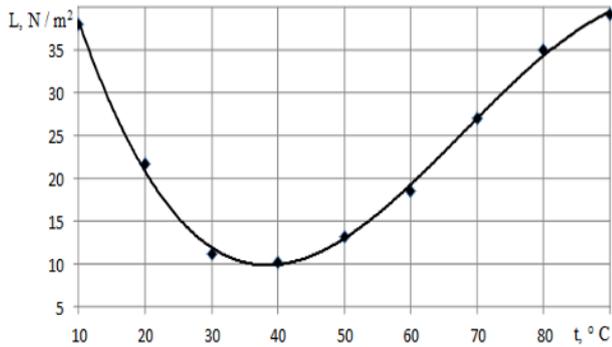


Fig. 5. Graphic dependence of stickiness (L) of condensed corn extract on its heating temperature (t)

The studies of the chemical composition of corn feed (pulp + extract) were conducted by an independent testing laboratory "PROVILAB" LLC "PROVIMI" (Moscow). Taking into account that the condensed corn extract has high acidity (pH – 4.0...4.2), it has been previously neutralized by calcium oxide (CaO) and sodium hydroxide (NaOH) when preparing corn feed. To neutralize one kilogram of corn extract (DM – 42 %) until a pH of 6.2–6.5 is reached, nineteen grams of calcium oxide and twelve grams of sodium hydroxide are used. At the same time, the content of calcium and sodium in the neutralized extract does not exceed the zootechnical standards for feed intended for feeding farm animals.

The results obtained when conducting laboratory studies to determine the dependence of the angle of repose and the bulk weight of corn feed prepared from starch production bypass on moisture are presented in the Fig. 6.

With an increase in corn feed moisture content from 5 to 80 %, the angle of repose increases from 28 to 49° due to an increase in the internal friction forces of the feed caused by the destruction of the native structure of starch grain. When reaching humidity of 80 % or more, the feed acquires a flow property.

An increase in the bulk weight with a decrease in humidity, characteristic of most hygroscopic granular materials, is also observed in the mixture of corn pulp and extract. When the moisture content of the raw feed varies from 5 to 80 %, the bulk weight of the mixture of corn mash with extract increases from 347 to 796 kg/m³. This is due to the saturation of raw food with water, the bulk weight of which is significantly higher than that of the dry mixture of corn mash with extract. It should be noted that in the range from 5 to 35 %, the bulk weight varies slightly.

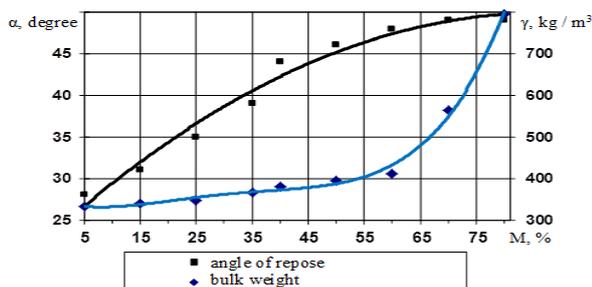
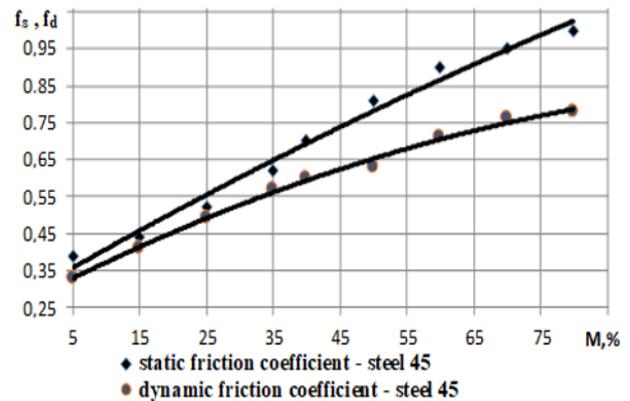
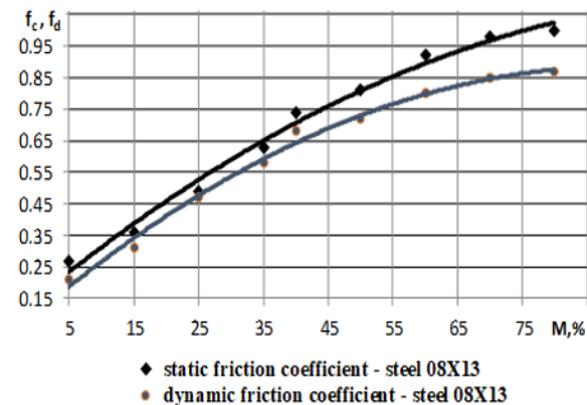


Fig. 6. Graphical dependence of the angle of repose (α) of the mixture of corn pulp with an extract on moisture (M)

According to the results obtained during the laboratory studies, the graphical dependences of the static and dynamic coefficients of corn feed friction on moisture on surfaces such as steel 45 GOST 1050-88 and steel 08X13 GOST 56532-72 (Figure 7).



A. Friction surface – steel 45 GOST 1050-88



B. Friction surface – 08X13 stainless steel GOST 56532-72

Fig. 7. Graphic dependences of the change in static (f_s) and dynamic (f_d) friction coefficients on moisture (M) of corn feed

With an increase in the moisture content of a mixture of corn pulp with an extract from 5 to 80 %, its static coefficient of friction for steel 45 GOST increases from 0.39 to 1.1, and that for steel 08X13 increases from 0.21 to 1.0. With the same parameters of moisture change, the dynamic coefficient of friction increases from 0.27 to 0.78 and 0.33 to 0.87 over the same friction surfaces. It should be noted that the friction coefficients of corn feed for stainless steel is less than for structural steel. The nature of the change in the static and dynamic coefficients of friction in both cases is the same and is explained by the fact that the chemical composition of the pulp, which is part of the feed, contains a significant proportion of starch. In the presence of free moisture, it swells and gelatinizes, creating the effect of material sticking to the steel plates.

The thermo-physical characteristics of the condensed corn extract were determined depending on the content of dry matter in it. When studying thermo-physical properties, the solids content varied from 5 to 50 % at the extract temperature of 30 °C.

The results of studies of thermo-physical properties of corn extract in the form of graphical dependencies are presented in Fig. 8.

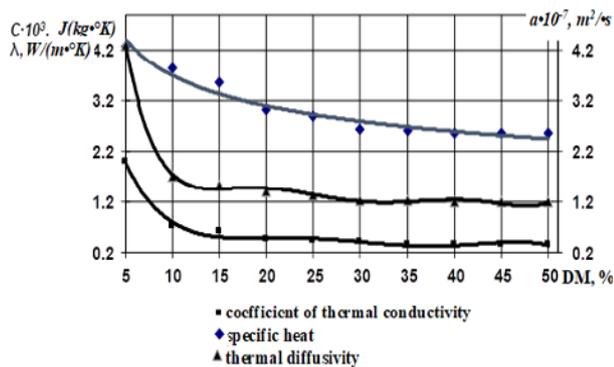


Fig. 8. Graphic dependences of thermal diffusivity (a), thermal conductivity (λ) and heat capacity (c) of corn extract on the content of dry matter (DM)

With an increase in the amount of dry matter from 5 to 50 %, the coefficients of thermal diffusivity and thermal conductivity decrease from 4.3×10^{-7} to 1.2×10^{-7} m²/s and from 1.99 to 0.35 W/(m·K) accordingly, and the specific heat of corn extract decreases from 4.27×10^3 to 2.55×10^3 J/(kg·K). The type of curves can be explained by changes in the nature of the formation of hydrogen bonds during heat transfer in liquid media [25].

The thermo-physical characteristics of the mixture of pulp with corn extract were determined at a temperature of 20 °C depending on the content of dry matter in it from 10 to 80 %. According to the research results, graphical dependences of the thermal diffusivity, thermal conductivity coefficient and specific heat capacity of corn feed on the content of dry matter in it were built (Figure 9).

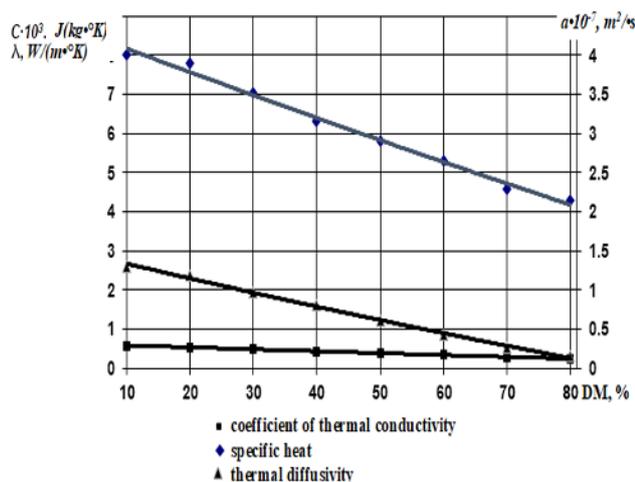


Fig. 9. Graphical dependence of thermal diffusivity (a), thermal conductivity (λ) and heat capacity (c) of corn feed on the content of dry matter (DM)

With a decrease in the proportion of dry matter and, consequently, an increase in humidity, all parameters of the thermo-physical properties of corn feed increase monotonically. This is due to the porosity of the material under study and an increase in the mass fraction of water, which has higher thermo-physical properties than the feed prepared from starch production bypass.

4 Conclusion

The results of the investigations make possible to estimate the interaction of the condensed extract when exposed to the working bodies, as well as in cases of heat transfer processes. It is shown that with decreasing temperature, the viscosity of the corn extract increases due to adhesion of its components, which characterizes it as a non-Newtonian flow of the extract. This is confirmed by a non-linear change in the stickiness of the condensed extract. The recommended temperature for processing corn extract is in the range of 45...500, when, due to its acidic environment, there is a slight denaturation of proteins, while its stickiness is 12...13 N/m² and the dynamic viscosity is 270...290 MPa·s.

The external friction coefficient is an important physical and mechanical characteristic of the mixture of the pulp and the extract. The change in the friction coefficients of the corn feed in the interaction with various surfaces of materials, depending on the content of dry matter. With an increase in the moisture content of the mixture of the corn pulp with the extract, the friction coefficients with interacting surfaces of materials increase, but only slightly.

The recommended values of friction coefficients allow calculating the geometry of storage bins and energy costs of processes such as transportation, grinding, dosing and mixing when preparing the raw corn fodder with humidity of 65...80 % are in the range of 0.7...1.0, and those of the dry fodder with humidity of 10...15 % are respectively 0.25...0.4. The values of thermo-physical characteristics of the corn extract and its mixture with the pulp are necessary for optimization and control of technological processes of their processing.

The thermo-physical properties were experimentally investigated and the specific heat capacity, thermal conductivity and thermal diffusivity of the condensed extract and its mixture with the pulp were determined, which for the extract were in the range from 4.27×10^3 to 2.55×10^3 J/(kg·K), from 4.3×10^{-7} to 1.2×10^{-7} m²/s, from 1.99 to 0.35 W/(m·K), and for the corn feed from 4,010 to 2,140 W/(kg·K), from 1.301 to 0.162 m²/s and from 0.573 to 0.250 W/(m·K), respectively. It has been established that the dependences of the specific heat capacity, thermal conductivity and thermal diffusivity of the extract and corn feed on the dry matter content decrease with increasing their concentrations.

The results of the studies can be useful in calculating the heat exchange process during the processing and thickening of the extract at evaporation plants, in the development of the technology and the selection of technical means of joint drying of the pulp and the condensed extract in the production of both dry and raw corn fodder from starch production bypass.

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