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The Influence of Increased Moisture on the Velocity of Drying, Dynamic Properties and Fluidization of Sunflower Seed

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SUMMARY

After following the consumption of energy in the process of drying cereals and oil plants throughout a number of years, it has been noticed that numerous factors have had an impact upon this process. This paper deals with the influence of increased moisture on the process of drying sunflower seed and consequently, on the overall consumption of energy expressed in tons of petrol equivalents (TEP). It has been concluded that, due to the mentioned reasons, the consumption of energy (TEP) has increased by approximately 20%.

In addition, the following mathematical model for water evaporation from sunflower seed has been calculated:

$$y = 23.298 - 1.174x + 0.018x^2, \text{ with } R^2 = 0.9838$$

The results of the research have shown a decrease in the volume of sunflower seed which can be expressed as $\Delta V = 15.98\%$, with the minimum reduction of 8.91% and the maximum one of 22.90%.

As a result of this, the pressure drops in the dryer varied a lot, from 300 to 400 Pa; in other words, the velocity of airflow during the period of fluidization differed from 1.61 m/s to 2.96 m/s.

KEY WORDS

sunflower, moisture content, drying velocity, breakage susceptibility

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Brzina sušenja, dinamičke osobine i fluidizacija u ovisnosti o vlazi sjemenke suncokreta

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SAŽETAK

Prativši višegodišnju potrošnju energije u procesu sušenja žitarica i uljarica uočeno je niz utjecajnih čimbenika na taj process. Ovaj rad obuhvaća utjecaj povišene vlažnosti na proces sušenja sjemenki suncokreta, a samim time i utjecaj na ukupnu potrošnju energije izražene u tonama ekvivalenta nafte (TEN). Utvrđeno je da zbog navedenih razloga potrošnja energije (TEN) povećana je za približno 20%.

Uz to izrađen je i matematički model otpuštanja vode iz sjemenki suncokreta koji glasi:

$$y = 23{,}298 - 1{,}174x + 0{,}018x^2, \text{ uz } R^2 = 0{,}9838.$$

U navedenim istraživanjima utvrđeno je smanjenje volumena sjemenke suncokreta koji iznosi $\Delta V = 15{,}98\%$, uz minimum od 8,91%, odnosno maksimum od 22,90%.

Posljedica toga je velika razlika u tlakovima koji su vladali u sušnici i oni iznose od 300 - 400 Pa, odnosno brzina zraka pri pojavi fluidizacije iznosila je od 1,61 m/s, pa do 2,96 m/s.

KLJUČNE RIJEČI

suncokret, vlažnost, brzina sušenja, dinamička svojstva

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INTRODUCTION

It is common knowledge that at the moment of harvesting, a sunflower seed has a higher level of moisture than the equilibrium one at which it can be stored. Consequently, drying is only a sequence and a completing stage of natural seed maturation, which was somehow prevented. In order to enable the longest possible period of storage of sunflower seed, drying process has to preserve the quality of seed and ensure the normal conditions which they require.

In the period from 1989 to 1995, about 19,200 hectares of soil surface were planted with sunflower. The average overall production was about 44,300 tons of sunflower seed, with the average crop of 2.4 t/ha. Also, 955 tons of oil were consumed on average, with the average seed moisture of 17% Statistički ljetopis (Statistical Chronicle), 1995; PROHES, 1996).

However, the year 1996 was particularly difficult at sunflower harvest time due to adverse weather conditions. The average levels of moisture in those sunflower seed that survived the unfavourable weather conditions in the area of West Slavonia were over 20%, and in some cases even 24%. Such high levels of moisture in seed presented an extra burden for reception and processing facilities.

RESEARCH OBJECTIVE

As far as moisture is concerned, freshly gathered sunflower seed always show a lack of uniformity. The research has shown that the same sunflower head consists of different seed which contain different percentages of oil. By analogy, all the seed on the same head do not contain the same levels of moisture. Unfavourable weather conditions and increased overall amount of work have emphasised even more this lack of uniformity in seed, which has rendered the drying of sunflower seed more difficult and caused the appearance of "spontaneous heating" during the period of storage.

Because of the above mentioned reasons, this paper deals with the following features:

- velocity of drying of sunflower seed at increased moistures;
- influence of drying air temperatures on changes in seed dimensions;
- research into dynamic resistance of sunflower seed;
- calculation of velocity and pressure of fluidization.

This paper's objective is to determine, on the basis of the results obtained, the equation for drying sunflower seed at increased levels of moisture, as well as the percentage of reduction in seed volume after the period of drying. Moreover, by dynamic pressure of sunflower seed, it is necessary to establish its mechanical resistance, plus the pressures and velocitys of the working medium which are needed to prevent the fluidization of seed at the stated levels of moisture.

REFERENCES

Convection drying is the oldest method of preserving the quality of food (Ensminger, M.E. et al., 1978). Thus the process of drying has to be carried out in such a way that the damage caused by it is reduced to a minimum. Researchers have been exploring this problem area for a number of years. The researches they have conducted have been based on either a thin (elementary) layer of individual seed or a deep-bed one. The authors show mathematical modelling of drying process (the loss of moisture in seed) by means of polynomial, exponential or logarithmic equations.

The constant features which are to be taken into consideration while analysing the thin-layer drying are the temperature and humidity of air, plus the mass of airflow passing through the thin moisture layer of seed.

Page (1949) suggests the exponential equation for the drying model of thin layer with the characteristics of constants of maize kernel and the ratio of kernel moisture, whereas Thompson (1967) suggests the exponential equation with the measured values and air temperature for drying. Li et Morey (1984) applies the exponential model which has been tested on dent corn. Byler, Anderson et Brook (1984) compares the curves of drying by means of a non-linear regression. They introduce a spherical model or the model of a sphere, plus a cylindrical model or the model of a parallelepiped. (Katić (1985/1) conducts a research into the relative relationship between the velocity of drying maize kernels of different hybrids and various temperatures of drying: exponential equations were used for all the measurement results.

The theory of applying a thin layer upon a deep-bed one was not used until the mid 60s when, according to Barrea et al., Hukill (1954) started developing the model of deep-bed layer simulation on the basis of the experience gained by doing research into the process of thin layer drying. This development has resulted in the introduction of computer models for the follow-up and simulation of the process.

Bloome, Gene (1971) analyse the effects of deep-bed layer drying with cold air and come up with a conclusion that such effects by all means depend on weather conditions, thus limiting the work with this system.

Parry et al. (1985) work out a differential equation for convection drying of kernel which is based on the assumption that airflow takes place in x-direction, while the kernel flow is in y-direction.

Katić (1985/2), on the basis of the research done over many years concludes that the results of measurements obtained in the elementary layer cannot be compared with the results from the deep-bed layer.

Babić Ljiljana (1989) concludes that there is no correlation between the kinetics of convection drying of the static deep-bed layer and the Fao group of maize hybrids.

Krička(1994) analyses the effects of drying ten hybrids in the deep-bed layer with hot air and comes up with the conclusion that there are big differences in water evaporation due to the movement of forces in the material. She works out the simulation models of drying ratios by means of polynomial and exponential equations.

During technological processes, from gathering to processing, a seed is exposed to various mechanical blows, as well as increased temperatures, which causes all kinds of damage and breakage in it.

This the American researchers Thompson and Foster (1963) carried out a research into the breakage of maize kernel at increased temperatures. The authors divided the damage within a kernel into three groups (a single breakage in kernel, a double breakage in kernel and a broken kernel). Katić (1971) explores the extent of damage of seed during the processes of drying and momentary cooling. Košutić (1981) concludes that there is a correlation between the tested physical-mechanical properties of the kernel and the corn cob and the content of water in the kernel. Katić (1985/3) explores the damage of a naturally dried kernel in comparison with an artificially dried one; he concludes that the damage of the latter one is two to four times bigger than that of the former one. Pliestić (1989) conducts a research into mechanical damage of a corn kernel on 27 kinds of different hybrids and concludes that the moisture of the kernel and the extent of dynamic pressure affect this type of damage on a kernel of corn, he introduces coefficient BS (breakage susceptibility) which is ratio of broken and whole kernel. Stroshine (1990) divides kernel damage into five categories, plus broken kernels.

A number of researchers (Beverloo, 1961, Ewalt and Buelow, 1963; Chang, 1984; Gregory and Fedler, 1987; Moysey, 1988 and others) studied the behaviour of both cereal kernels and oil plant seed during their passage through differently shaped and sized orifices. On the basis of their research they calculated experimental (empirical) equations which were then reduced to one common equation described in ASAE Data D 274 (1989): "The flow of kernels and seed through orifices".

The researchers Bakker-Arkema et al. (1969) studied mutual relations between static pressure and the flow of working medium (air) in packed beds of granular biological materials. The first part of their study that was carried out on cherry pits involved the research into equations which mostly describe the factors caused by the effect of the pressure through the static layer of biological materials. The second part of their work presents both an experiment and a comparison of the results obtained with the equations made.

Pabis (1982) studies the occurrence of fluidization in the process of drying agricultural materials (produce) in fluidized layer. He claims that for the process of drying in fluidized layer it is extremely important to know the medium diameter of particles. The author investigates the process of fluidization on the wheat whose level of moisture is 14%. Using the insight gained by the afore mentioned authors, he concludes that a pressure drop in the layer of agricultural materials follows certain rules of mutual relations between the velocity of airflow through the layer and its height.

Židko et al. (1982) studied, among other things, the hydraulic resistance of a kernel layer. They claim that in most cases such a resistance depends on the length of the layer exposed to airflow, the velocity and parameters of the air, the porosity of kernel weight and the surface of the kernel (its roughness).

Kumar and Muir (1986) studied the resistance of wheat and barley layers to airflow.

Jayas et al. (1987) conducted a laboratory research into the resistance of two variations of rapeseed to airflow direction.

Gunasekaran et al. (1988) studied the resistance to airflow through a sorghum layer. After completing their research, they concluded that the resistance of the layer rose with the increase in the quantity of the working medium, as well as with the increase in the height of the layer. They also worked out that a drop in the pressure goes up faster with an increase in the velocity of the working material than with an increase in the height of the layer of the material.

Sokhansanj et al. (1990) studied the resistance of a lentil layer to airflow. They also studied the effect of lentil's moisture, ways of loading and airflow direction on pressure drops in the layer of the material.

The researchers Yang and Williams (1990) conducted some laboratory research into the effect of both density and porosity of sorghum layer on the resistance to airflow through the layer. They also tried to develop mathematical models for pressure drop through sorghum layer as a function of air velocity, i.e. the quantity of airflow and the density of the material in loose spilled condition.

Chang et al. (1991) investigated the levels of airflow through differently shaped vertical and horizontal orifices. They did their research on two variations of wheat, maize and sorghum and on one variation of soybean.

Jayas and Muir (1991) studied the method which involves the effect of airflow direction into the mathematical model that estimates a pressure drop in layers of various field crops. Several elementary equations were used to mathematically express a drop in airflow pressure (Shedd, Hukill and Ives, Ergun). The authors calculated a flow equation for threedimensional configuration.

Katić (1992), after studying the resistance of layers of different materials to airflow, says that it depends on the height of a layer, the porosity and shape of a kernel, as well as on the velocity of the air which flows through the layer of a material. He also makes a mention that some of the difficulties of determining the resistances are caused by the lack of uniformity among kernels which biologically appear in different shapes and sizes.

Pliestić (1995) studies the resistance of the 200 mm thick layer of the Bc 492 maize kernel during the process of drying, plus the velocity of the fluidization of the layer. He concludes that a pressure drop (p) and the velocity of the beginning of fluidization decrease linearly with a reduction in the height of the layer (h) of the material and the moisture of samples (n) by drying. He also finds out that a pressure drop and a fluidization velocity depend on the moisture of a sample and the shape of a particle of the material.

However, it can be noticed that references on oil plants (sunflower in particular) in the process of drying, their dynamic resistance and fluidization, are almost non-existent.

METHODOLOGY

The velocity of drying sunflower seed

The velocity of drying sunflower seed was tested by means of a laboratory dryer in a fifteen-centimetre-thick stationary layer. The moisture of the seed was measured by a standard method just before drying. The process itself, that is to say, each sample under experiment, went both through the stage of drying and the stage of cooling in the course of drying.

The stage of drying was followed-up by means of the following parameters:

1. temperature of air at the entrance to the dryer t_1 = 60°C
2. velocity of air at the output of the dryer v = 1,0 - 1,2 (m/s)

The velocity of water evaporation from the velocity was measured every five minutes until the moisture was approximately 6% (w.b.). The samples were divided into ten groups, each of whom was tested throughout ten repeats (100 samples altogether). After drying, the seed were cooled by means of the surrounding air.

The influence of air temperatures on changes in dimensions of seed

The dimensions of sunflower seed were measured out of all the 100 samples under experiment in such a way that twenty samples of seed were picked at random and then measured both before and after drying. Each seed was measured in its length, height and bulk. On the basis of the measured dimensions, the approximate volume, i.e. the difference in the volume of sunflower seed, was determined.

Testing of dynamic resistance of sunflower seed

The dynamic pressure of the seed was tested by means of a centrifugal drum. The mechanical damage of the seed was established by a simulation of their fall into a silo bin. The number of revolutions was 1800 rpm during the simulation of the fall of a sunflower seed from the height of 46m at the moment when it reaches the bottom of the silo bin at the velocity of 30.2 m/s. The experiment was carried out in such a way that 50 seed were selected five times out of each sample and then dropped down the drum. After their passage through the drum and on establishing the breakage rate, the ratio of the whole seed to the broken ones was determined.

Measuring of velocity and pressure of fluidization in sunflower seed

The velocity of air at the beginning of fluidization was measured by means of an anemometer and a deflector at the output of the dryer and it was determined when the first seed started to fluidize. The air pressure in the dryer was taken by means of a manometer, just before it entered the seed layer.

RESULTS

Velocity of drying sunflower seed

Table 1 contains the measured values of overall measurements of the surrounding air temperatures (t_0), relative air humidity (j_0), velocity of the air at the output of the dryer (v_2), temperatures of the air at the entrance to the dryer (t_1), temperatures of the seed at the end of

Table 1. Parameters environment temperature and velocity of drying air moisture of the seed

Samples of Sunflower	t_0(°C)	φ_0 (%)	v_2 (m/s)	t_1 (°C)	θ_1 (°C)	w_1 (%)	w_2 (%)
1/10	20,6	30	0,96	57,0	53,7	24,02	5,56
2/20	22,7	36	1,16	63,7	58,7	24,02	4,52
3/30	21,1	35	1,18	61,4	55,8	22,88	5,85
4/40	22,1	37	1,31	62,8	53,2	23,01	4,92
5/50	22,7	35	1,10	58,1	47,3	21,77	6,09
6/60	22,04	37	0,99	57,7	50,5	22,84	4,65
7/70	19,06	38	1,18	57,1	53,1	22,64	5,92
8/80	22,02	36	1,19	61,4	55,1	23,87	5,79
9/90	22,1	32	1,27	61,3	55,6	21,43	5,79
10/100	22,8	32	1,16	61,0	50,4	22,49	5,16
Average	21,76	34,8	1,15	60,15	53,34	22,897	5,425

Table 2. The velocity of evaporation of moisture from sunflower seed:

Samples of Sunflower	Time (min)						Equation: y=
	0,01	5	10	15	20	25	
1/10	24,02	19,44	14,22	10,07	7,21	5,74	$24{,}394\text{-}1{,}203x+0{,}018x^2$
2/20	24,02	19,44	13,36	8,62	6,42	4,52	$24{,}556\text{-}1{,}326x+0{,}021x^2$
3/30	22,88	17,06	12,06	9,32	7,38	5,85	$22{,}793\text{-}1{,}271x+0{,}024x^2$
4/40	23,01	17,88	11,04	7,17	5,07	4,92	$23{,}621\text{-}1{,}544x+0{,}031x^2$
5/50	21,77	17,93	11,39	8,88	6,58	6,09	$22{,}236\text{-}1{,}261x+0{,}024x^2$
6/60	22,84	18,02	11,29	9,02	7,37	4,65	$22{,}984\text{-}1{,}267x+0{,}022x^2$
7/70	22,64	18,42	14,27	9,03	6,13	5,92	$23{,}216\text{-}1{,}167x+0{,}018x^2$
8/80	23,87	16,53	11,21	7,70	5,87	5,79	$22{,}825\text{-}1{,}619x+0{,}036x^2$
9/90	21,43	15,02	10,77	7,47	5,85	5,79	$21{,}360\text{-}1{,}379x+0{,}03x^2$
10/100	22,49	16,53	11,29	8,72	6,59	5,16	$22{,}399\text{-}1{,}308x+0{,}025x^2$
Average	23,08	17,63	14,86	8,60	6,45	5,44	$23{,}298\text{-}1{,}174x+0{,}018x^2$

$r = 0.9919$ $R^2 = 0.9838$

Table 3- Mean values of volume dimensions and volume percentage in sunflower seed before and after process of drying:

Samples of Sunflower	Before drying w_1 (%)	length (mm)	width (mm)	diameter (mm)	V_1 (mm^3)	After drying w_2 (%)	length (mm)	width (mm)	diameter (mm)	V_2 (mm^3)	ΔV (%)
1/10	24,02	9,74	5,01	3,40	27,65	5,56	9,47	4,47	3,05	21,53	22,13
2/20	24,02	9,79	5,15	3,54	29,74	4,52	9,48	4,79	3,18	24,06	19,10
3/30	22,88	10,40	5,20	3,40	30,64	5,85	10,04	4,92	3,39	27,91	8,91
4/40	23,01	10,08	5,15	3,33	28,81	4,92	9,74	4,93	3,20	25,58	11,20
5/50	21,77	9,99	4,98	3,31	27,44	6,09	9,73	4,67	3,21	24,23	11,70
6/60	22,84	10,27	5,23	3,36	30,07	4,65	9,95	4,77	3,10	24,52	18,47
7/70	22,64	10,45	5,24	3,35	30,57	5,92	10,01	4,90	3,12	23,34	17,11
8/80	23,87	10,11	5,50	3,78	35,03	5,79	9,84	5,10	3,50	29,27	16,43
9/90	21,43	10,17	5,35	3,57	32,37	5,79	9,66	5,07	3,52	28,73	11,84
10/100	22,49	10,18	5,44	3,60	33,22	5,16	10,03	4,88	3,14	27,61	22,90
Average	22,89	10,12	5,23	3,46	30,55	5,43	9,79	4,85	3,24	25,68	15,98

Table 4. Mean values of dynamic susceptibility in sunflower seed

Samples of Sunflower	T_{1000} (g)	Total weight (g)	Size of samples	Breakage weight (g)	Breakage (%)	Whole weight (g)	Whole (%)	Coefficient BS	w_2 (%)
1/10	50,4	2,52	50	0,76	41,2	1,76	58,8	0,7	5,56
2/20	54,4	2,72	50	0,72	33,2	2,00	66,8	0,5	4,52
3/30	57,6	2,88	50	1,28	37,2	1,60	62,8	0,6	5,85
4/40	45,2	2,20	50	0,92	42,4	1,34	57,6	0,7	4,92
5/50	51,6	2,58	50	0,96	36,8	1,62	63,2	0,6	6,09
6/60	50,0	2,50	50	1,08	44,0	1,42	56,0	0,8	4,63
7/70	53,2	2,66	50	1,02	40,4	1,64	59,6	0,7	5,92
8/80	49,6	2,48	50	0,96	40,4	1,52	59,6	0,7	5,79
9/90	54,8	2,74	50	0,96	34,8	1,78	65,2	0,5	5,79
10/100	54,8	2,74	50	1,18	39,6	1,56	60,4	0,6	5,16
Average	52,2	2,60	50	0,984	39,0	1,624	61,0	0,6	5,42

the drying process (,_1), as well as both the initial (w_1) and final levels of moisture of the seed (w_2).

Table 2 shows the measured values of the velocity of water evaporation from sunflower seed with regard to time.

The influence of drying air temperatures on changes in seed dimensions

The length, width and height of the seed (mm) throughout twenty repeats for each sample were measured just before drying and then after the process

Table 5. Mean values of air pressure drop in the dryer and the velocity of sunflower fluidization:

Samples of Sunflower	w_2 (%)	T_{1000} (g)	p (Pa)	v' (m/s)
1/10	5,56	50,4	400	1,69
2/20	4,52	54,4	380	2,96
3/30	5,85	57,6	323	1,91
4/40	4,92	45,2	296	1,48
5/50	6,09	51,6	320	1,91
6/60	4,65	50,0	350	1,61
7/70	5,92	53,2	340	1,91
8/80	5,79	49,6	300	1,69
9/90	3,79	54,8	386	1,69
10/10	5,16	54,8	323	2,24
Average	5,22	52,16	341,8	1,91

of drying. The values obtained were then used to calculate the volume of the seed (mm^3), as well as the percentage of its reduction. Table 4 shows the measured values.

Testing of dynamic resistance of seed

While testing the dynamic resistance of the same samples (1 - 10) of the dried sunflower seed, the research was carried out in the n = 1,800 rpm centrifugal drum, at the same temperatures and relative surrounding humidity that were used in the course of drying. The percentage of breakage (i.e. of whole seed) was tested throughout five repeats per fifty seed. Table 3 contains the mean values of the results obtained for each dried sample.

Testing of velocity and pressure of fluidization in sunflower seed

Measurements of the pressure and velocity of fluidization in sunflower seed were repeated three times for each sample. Table 5 shows the mean values of the pressure in the dryer and of the fluidization of sunflower seed.

DISCUSSION

Drying, as well as changes in dimensions of sunflower seed, during the process of drying were tested in laboratory conditions at average air temperatures of 21.70 and relative humidity of 35%.

In the course of the experiment, the air temperature at the entrance to the dryer was 60.15°C, while the velocity of the working medium was 1.15 (m/s) with n = 100 repeats. The temperature of the seed at the end of drying process (outside of airflow) was 53.3°C. The moisture of the seed at the beginning of drying was 22.897%, whereas after drying it was 5.425%. The mathematical model for water evaporation from sunflower seed in all samples was as follows: $y = 23.298 - 1.174x + 0.018x^2$, with $R^2 = 0.9838$ (Blum, Geone, 1971; Katić, 1985; Krička, 1994).

If the values obtained are compared with the approximate consumption of energy for drying of sunflower seed in the period from 1988 to 1994 of 955 TEP (Krička, Pliestić, Katić, 1996), it means that, due to the process of drying, the Republic of Croatia had to spend over 20% energy more, i.e. 190 TEP on average.

In the period of testing, the average volume of sunflower seed before drying at the moisture of 22.89% was 30.5 mm^3, whereas after drying, at the moisture of 5.43%, it was 25.68%. Although the difference was V = 15.98%, it varied from 8.91% to as much as 22.90%, which can be supported with the reports by a group of authors.

Such a big difference in dimensions, i.e. the volume of sunflower seed, had an effect on its dynamic properties ant it caused fluidization. The average ratio of the broken seed to the whole ones, at the moisture of 5.43%, was 39.0:6.10. However, due to the above mentioned reasons, that ratio differed from 33.2:66.8 to even 44.0:56.0.

There is no doubt that such a high breakage ratio must have an effect in the period of conservation and storage.

This lack of uniformity among the samples of sunflower seed caused big pressure fluctuations in the dryer that varied from 300 to 400 Pa, which proves that resistance to airflow through the layer depends on porosity, as well as on the shape of the seed (Chang et al., 1991, Jayas and Muir, 1991, Katić, 1982, Pliestić, 1995). Consequently, there is a big difference in the velocity of air depending on the beginning of fluidization. Thus in the group of samples 6, fluidization started as early as at the velocity of 1.61 m/s and the moisture of 4.65%, whereas in the group of samples 2, it began as late as at the velocity of 2.96 m/s and the moisture of 4.52%. Fluidization obviously depends above all on the shape and size of a particle of the material (Pliestić,1995)

CONCLUSION

On the basis of the research that we conducted into the influence of increased moisture on energy consumption, the mathematical modelling of drying equations, changes in dimensions, volume and dynamic properties of sunflower seed, as well as the resistance within the dryer and the velocity of fluidization, we have reached the following conclusions:

Owing to increased moisture in sunflower seed, the Republic of Croatia had to spend in 1996 approximately 20% more of energy equivalents (TEP) than in the previous years.

The mathematical model for water evaporation from sunflower seed was calculated at increased moistures (w = 22.89%) and is $y = 23.298 - 1.174\ x + 0.018x^2$, with $R^2 = 0.9838$.

In the process of drying, from the initial moisture of 22.89% to the final one of 5.43%, the volume of sunflower seed decreased by 15.98%, with the minimum reduction of 8.91% and the maximum one of 22.90%.

The dynamic resistance of seed with the average 1,000 seed weight of 52.2 g was 39.0:61.0 (at the moisture of 5.43%). The minimum ratio of the broken seed to the whole ones varied from 33.2:66.8 to as much as 44.0:56.0.

The heterogeneity of seed mixture in the dryer itself brought about a big difference in pressures that varied from 300 to 400 Pa, which resulted in a big fluctuation of the air velocity. This velocity was 1.61 m/s at the moment of fluidization and went up to 2.96 m/s later on, which made the process of drying, i.e. the regulation of the dryer, more difficult.

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