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INTENSIVE ENERGY SAVING METHOD OF GRAIN DRYING

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Abstract

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The method of drying of grain and removal of moisture which is based on receiving and processing of arising thermal processes described by the thermodynamics equation is developed. For carrying out pilot studies, it is developed the transistor – thyristor device, which consists of the control unit, the converter of frequency, the bunker with the screw in it that has helix surface, inductor windings, and a hydrometer. The algorithm of receiving and data processing is developed in the MATLAB software. It is a first time when the Maxwell's formula is suitable for calculating a heat taken from grain moisture.

Key words: Grain drying, electromagnetic induction, the amount of generated heat, the Maxwell formula

Abbreviations: W – humidity of grain, %; I – density of a stream of moisture; k – kinetic coefficient of moisture transfer (proportionality coefficient), depending on physical and chemical properties of a material; δ – coefficient of thermo-moisture transfer of a material; E – electromagnetic intensity V/m; tgδ – losses dielectric angles characterized by the environment and frequency of microwaves generation (it completes 90º angle of phase shifting between current and tension in a condenser between facings of which the material is placed); ω – the settable frequency of the microwave generator, GHz; C_1 – condenser capacity at the time of grain loading; C_2 – air condenser capacity; ε – dielectric permeability of wet grain; ε_1 – dielectric permeability of material; ε_0 – dielectric permeability of absolutely dry grain; ε_0 – dielectric permeability of absolutely dry grain; a – constant; b – constant; Q – amount of emitted heat; σ – coefficient of losses

Introduction

Kazakhstan is one of the most important producers of hard wheat. Nowadays the grain yield in Kazakhstan is 20 million tons, and in the best years yields were collected up to 34 million tons. The main part of this grain is exported to the different countries of the world. Considering that the major grain-producing regions are located in the rainy northern part of the country, harvesting encounters a problem of high such as increased grain moisture, reaching up to 20%. At harvest in late of August or at the beginning of September moisture in the straw exceeds the humidity of the grain by for 10%-20%, while rice harvesting grain moisture and the difference stems happens even triple (Hemisatal, 2012).

The alternative to existing technologies offers use of a high-frequency electromagnetic field which not only has no emissions in the atmosphere, but also influences directly on internal part of heated body (grain) rather than on a surface as in traditional ways, and efficiency will increase with increase in humidity of grain. For this purpose we offer the transistor– thyristor microwave generator which unlike the magnetron generator, has higher efficiency since the most part of energy isn't spent for heating of a filament of the magnetron (Figure 1).

Grain moves in a cylindrical contour from dielectric by helical screw surface on which the screw angle of lead always corresponds to the current value of a corner of friction. For example, in the first phase, coming grain "sticks"

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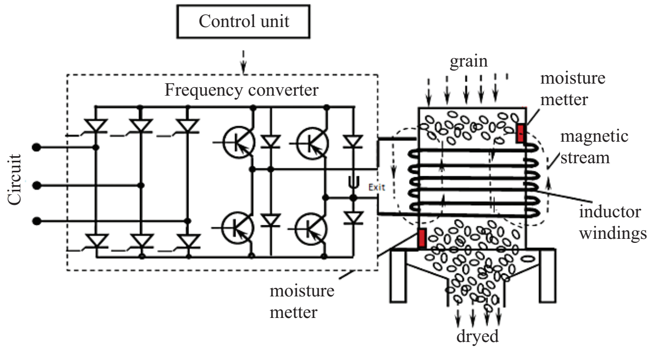

Fig. 1. The scheme of the microwave plant with the screw of a helical surface

to a screw surface, then in process of drying the coefficient of friction decreases and grain slowly moves on the following level. Thus, in the lower part of this helical surface the grain will descend with required humidity. If grain has very high humidity, the multicascade plant could be used. For example, the 1-st cascade dries from 26% to 20%, the second from 20% to 17% and the third from 17% to 12–13% humidity respectively. The last years there is a need for highly effective and energy saving systems of transformation of the electric power of industrial frequency for the induction heaters possessing higher technical and economic rates, and also smaller material and financial inputs on production.

The rectifier and the inverter represent the frequency converter. Use of the transformer in primary chain sharply increases the cost of all induction heaters and leads to increase of the mass-dimensional sizes (Kurushin and Plastikov, 2010).

There are the frequency convertors where is the transformers in use to decrease voltage in it. The task consists in creating, such converter of frequency where the lowering transformer wouldn't be used.

Feature of induction input of energy is possibility of regulation of a spatial arrangement of a zone of course of vortex currents. First of all, vortex currents proceed within the area covered by the inductor. Only that part of a body which is in magnetic communication with the inductor irrespective of the general sizes of a body heats up. Secondly, depth of a zone of circulation of vortex currents and, therefore, a zone of allocation of energy depends, except other factors, from the frequency of current of the inductor (increases with low frequencies and decreases with frequency increase). Efficiency of transmission of energy from the inductor to heated current depends on gap size between them and rises at gap size reduction. Induction heating apply to superficial tempering of steel products, through heating under plastic deformation (forging, stamping, pressing etc.) melting of metals, heat treatment (annealing, distribution, normalization, tempering), weldings. Indirect induction heating apply to heating of processing equipment (pipelines, storages etc.), heating of liquid environments, drying of coverings, materials (for example, wood). The most important parameter of installations of induction heating is frequency. For each process (superficial tempering, through heating) there is the optimum range of frequencies providing the best technological and economic indicators. For induction heating are used frequencies from 50 Hz to 5 MHz, (Barroso and de Paula, 2010).

Basis of the theory of drying of grain are regularities of transfer of warmth and moisture in a weevil at interaction by its heated gases, with hot surfaces, and also in processes of radiation by thermal and electromagnetic waves in the presence of phase transformations.

Process of drying of grain, as well as any wet materials is not only heat physical, but also technological process in which nature of course the crucial role is played by a form of communication of moisture with a material. Studying of process of drying of grain can be limited by the phenomena of movement of moisture in a material, a vaporization and diffusion of vapors of moisture from a grain surface in air. These processes generally open the mechanism of process of drying.

Drying, heating and grain cooling – processes which are accompanied by change of temperature and humidity of grain, and also density of streams of warmth and moisture in time. During drying of grain there are temperature and moisture content gradients in it under the influence of which there is a transfer of warmth and moisture in grain, there is thermal and volume tension may occur, (Metaxas and Meredith, 1983).

Along a surface of a damp weevil the agent of drying moves with certain parameters. Warmth from the agent of drying is transferred in the convective way to a weevil; its surface heats up, and the part of the moisture, which is at a surface, evaporates. As a result on thickness of a weevil differences of moisture content, temperature and pressure under the influence of which moisture is continuously brought to a surface where evaporates are created. Steam molecules diffuse through a boundary layer then absorbing by the agent of drying. The indispensable condition of process of removal of moisture from a surface of a weevil is an existence difference between fractional pressure at its surface *Pм* and in the agent of drying *Pn*.

Moisture evaporates not from a weevil surface, and from some zone 3, which is located in peripheral part of the weevil. Moreover, the position of this zone doesn't remain invariable: it gradually moves (goes deep) in a weevil. Many researchers connect the beginning of deepening of the zone of evaporation with the removal of the bounded moisture from grain. When the zone of evaporation is deepening the surface weevil remains dehydrated, deprived of a protective factor and therefore can heat up to high temperatures, (Molnar and Numerical, 2006).

The intensification of transfer of warmth and moisture promotes drying acceleration, but because of this arising tension can lead to grain deterioration – formation of cracks, splitting, which can influence to grain integrity in the end etc. Therefore it is important to establish an optimum mode of drying.

Warm and moisture transfer when drying grain submits to the general laws of a heat mass transfer and is its special case. The uniform theory of a heat mass transfer forms a theoretical basis for them. On the basis of this theory processes of transfer of warmth and moisture in grain can be described analytically. Such description allows determining temperature and moisture content in any point of grain or a grain layer at any moment, to find their gradients and change in time, to calculate density of streams of warmth and moisture, to predict further development of these processes. At the same time the mathematical description of processes in grain and a grain layer there are certain difficulties as grain is non-uniform on structure and properties. Thereof various sites of grain have different conductivity and possess anisotropic properties, i.e. different conductivity diversely.

Grain has a complex geometrical form, and the grain layer represents the disperse environment, because of this the grains in weevil are focused in space randomly. Besides, processes of transfer of warmth and moisture in grain are interconnected and mutually influence one another and heat physical and moisture exchange properties of grain depend on its humidity and temperature, owing to what the differential equations of warm moisture transfer have nonlinear character.

In the process of drying of grain, there is a heat moisture exchange between a surface of grain and environment, and also warmth and moisture movement in it. External moisture exchange is caused by difference of a factional pressure at a surface of grain and in environment. Moisture movement from inside layers of grain to a surface depends on its structure and the properties in turn depending on forms of communication of moisture with grain. Moisture from inside layers usually moves to its surface at the same time with a stream of the warmth circulating in same direction, or is more often in the opposite direction. By knowing regularities of thermo-moisture-transfer it is possible to achieve ensuring high-quality process of drying of grain with the minimum costs of energy of this process.

Increase of production of grain in Kazakhstan is impossible without development and improvement of technology of storage of grain. Adverse climatic conditions such as high humidity are common for northern regions of our country. Storing grain in that condition depends on degree of perfection of technology of storage in which the main place is taken by grain drying.

Specific properties of grain in the moisture containing in it which removal is connected with heat expense by its evaporation. In this regard in practice of a grain drying there are various technologies of thermal drying in use. Thermal impact on a grain needs special attention to prevent negative changes of a condition of biochemical substances of the grain. The task consists in justification of rational technology and the optimization of modes of drying providing full preservation of quality of grain and its safety as raw materials for production of the most mass food of the people, and forages for animals.

In the past for many years development of technologies of drying of grain was focused on acceleration of process of drying that objectively was caused by a lack of drying capacities and a congestion of big mass of the fresh grain harvesting.

Despite the changed conditions of preparations of grain, decrease in rates of its receipt on elevators and bakeries, the considerable part of grain is still dried at quite rigid temperature modes which are perniciously reflecting in its quality.

Proceeding from common goals, decrease in losses of grain and improvement of quality of grain the major tasks of increase of efficiency of technologies of drying of grain can be successfully solved only on a scientific basis with expansion of researches of properties of grain as object of drying, establishment of kinetic regularities of process of drying, creation of bases of management by technological properties of dried-up grain, with development of ways of power saving and resource-saving.

Thermal drying is interfaced to intensive impact on all biological system of grain as live organism. The orientation and changes in grain significantly depends on applied technology of drying and can have either positive or negative consequences.

Available literary data on kinetics of drying of grain aren't coordinated changes of its technological properties. In an assessment of efficiency of technology of drying the indicator of quality of the dried grain in many cases isn't paramount. Operating temperature modes of drying and limit values of decrease in humidity of grain for one cycle of drying are rigidly regulated out of communication with regularities of kinetics of process of drying. There are no quantitative characteristics of interrelation of speeds of heating and grain drying. Duration of drying pays off only proceeding from the set decrease in humidity of grain without the speed of its heating. There are no data on unevenness of heating on thickness of a layer of grain during drying in widely applied “mine” type dryers.

In practice of agricultural production use various receptions for an intensification of process of drying of grain, like: use of the electro-activated air, preliminary heating of grain, using of recirculation modes, pumping out of a zone of drying, change of gas structure of the drying camera and many others. Among them influence by a magnetic field of the ultrahigh frequency (microwaves) is even more often used recently. In our country there is a certain experience of use of the microwave oven of fields is saved up when drying grain. In result of progress has been developed installations, allowing to improve the existing industrial dryers applied at the agricultural enterprises are as a result developed. Also been studied possible use of microwaves for pre-seeding processing of seeds.

Materials, Methods and Results

Authors of article made experiments of drying of grain by currents of high frequency. At high-frequency drying the supply of heat is carried out by a field of electric current with ultrahigh (2000–2500 MHz) frequencies that is a consequence of the theory of Maxwell which says that “the higher electromagnetic induction frequency, the more heat is transferred to a heated body”, (Soproni et al., 2009). Therefore to use currents of the ultrahigh frequency (microwave) is much more effective. Damp materials that have plant origin are dielectrics, which have some properties of semiconductors. Ions of electrolytes, electrons, the molecules of polar and unpolar dielectrics possessing the dipolar moments are their part. In an electromagnetic field dipoles settle down an axis along a field. Getting to a variation electromagnetic field, they make oscillating motions, aiming to follow fields.

At drying process the material is located between condenser to which currency with high or ultrahigh frequency feeds. Facings have opposite charges therefore ions and electrons move in a material to this or that facing. At charge change on facings they move in opposite directions, As a result, friction occurs with heat release. Dipoles in AC electric field will fluctuate from one to other side, there is as well as a result, friction occurs with heat release. The energy of electromagnetic waves spent for overcoming of these friction, will turn into heat.

For measurement of key parameter of the environment on which the electromagnetic field influences, is a dielectric constant. There was created a device in the laboratory of Kazakh National Agricultural University for measurement of a dielectric constant of grain of straw and ears at different stages of humidity. It is the condenser with plates of 200x200 mm and a gap between them 5 mm. Initial capacity of the condenser is 18.185 pF, measurement of changes of capacity made by E12A-1A Bridge with accuracy of 0.001pF.

$$\varepsilon_1 = \frac{C_1}{C_2} \qquad (1)$$

It was established that the electric resistance of a grain layer decreases when temperature increase, that is more noticeable, when humidity of grain is going down that is explained by decrease in electric conductance of grain due to moisture evaporation from the grain.

Respectively with increase of temperature value of dielectric permeability increases as well, and increases quicker, the more moisture content in the grain.

Dielectric permeability of damp wheat according might be calculated by the following formula:

$$\varepsilon = \varepsilon_0 + k \times W \qquad (2)$$

The similar formula is recommended from him to find a tangent of angle of losses of wheat. Noted dependence of conductivity of grain on humidity and offers a formula:

$$\sigma = \alpha \times \exp(b \times \omega) + C \qquad (3)$$

In electric field with high and ultrahigh frequency, heating of particles of plant matter takes place in a few seconds. Under the influence of high frequency alternating electric field an adjustable material’s heating occurs. Because of moisture evaporation, heat and mass exchange with environment, blankets get dehydrated and lose heat. Therefore, temperature and humidity inside of a material is higher, than outside it. Gradients of temperature and moisture leads to that moisture moves from the center to surface of a grain. Thus, unlike convective drying, the direction of both gradients coincides. This intensifies drying process (Ragha et al., 2011).

Using this way of drying evaporation spreads the whole volume. Having changed field’s intensity regulation of a material’s temperature during drying is possible.

The amount of emitted heat (Q) is determined by Maxwell’s formula. Taking into account t that grain’s drying depends on intensity, dielectric properties of the environment, frequency of a generator and grain humidity, the following formula 4 is derived:

$$Q = 0.555 \times E^2 \times \omega \times k \times \mathrm{tg}\delta \qquad (4)$$

Dielectric permeability defines ability of transition of energy of electromagnetic waves to warmth and ability of a material to react to an external electromagnetic field depends on physical and chemical properties, on temperature and moisture content of a material, on frequency and intensity of electric field. Change of dielectric permeability leads to change of an operating mode of drying plant. Dielectric permeability of dry materials is much less, than waters. The less value of dialectical permeability the deeper electromagnetic oscillations of ultrahigh frequency current can penetrate deep into grain.

Discussion

On the basis of these provisions experiment on use of change of frequency for grain drying was made. The purpose of experiment was gathering curves of drying of grain at changing independent factors. As independent factors dielectric permeability of grain, generator frequency (ω), coefficient of losses (σ) and initial humidity of grain (W) are accepted (Trisvyatsky, 1975).

Further, despite high initial moisture content of grain, drying proceeds throughout process with a decreasing speed of evaporation of moisture with continuously increasing temperature of grain that finds reflection in character of the received curves of drying, as a result of carrying out experiment, dependence between coefficients of losses (σ) is received with various frequencies processed on Excel program (Figure 2).

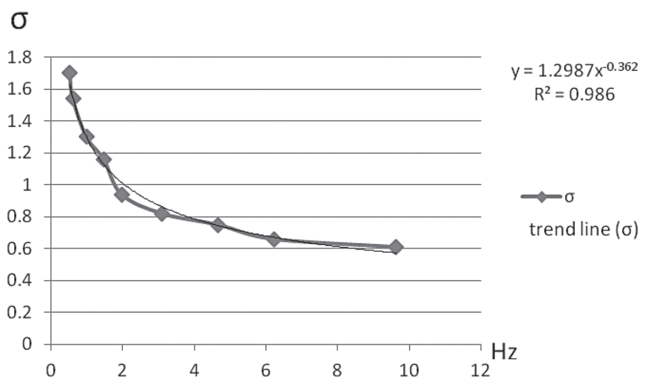

Fig. 2. Dependence of coefficient of losses from various frequencies

We began analyzing the dependence of the coefficient of losses under the influence of emitter to wet grain, with its different frequencies. First of all it should be noted high coefficient of a concordance 0.986 that says about strict functional dependence between the frequency and energy of moisture spent for heating in grain, blue graph. Studying the received dependence we observe that in the range from 0 to 120 MHz this curve has monotonously decreasing character and then "asymptoting" at the level of 0.6 black graph. Here we got very important conclusion that at further increase in frequency the coefficient of losses (σ) is not changing, therefore, considering that our device works in GHz range coefficient of losses will be constant, i.e. equal 0.6. So why at studying influence of humidity of grain on coefficient of losses (σ) we can consider with confidence that frequency doesn't influence the accuracy of measurements.

Next experiment was made at change of coefficient of losses (σ) from humidity and data processed in the Excel program, as a result of experiment the curve of drying of grain was found, Figure 3.

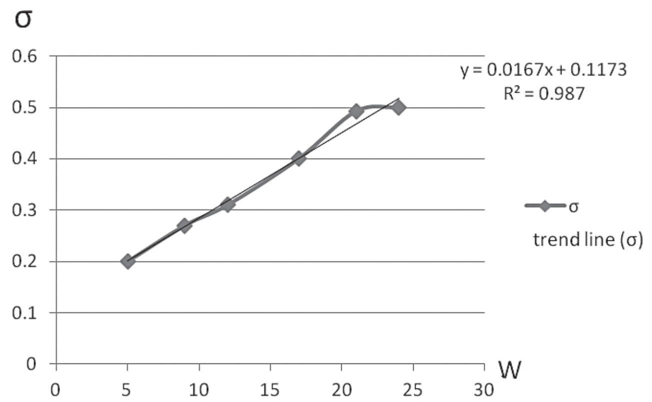

Fig. 3. Dependence of coefficient of losses from humidity of grain

Conducting an experiment on the change of coefficient of losses (σ) from humidity of grain in the real range from 5 to 25% – it is the blue graph. We see that this dependence has especially linear character with coefficient of a concordance 0.98 that says about strict functional dependence, black graph. This function is approximated by the linear equation:

$$k \times \text{tg}\sigma = 0.016 \times W + 0.13 \quad (5)$$

From the equation we found that the amount of heat received by moisture in a weevil increases with increase in its humidity. It says about high efficiency of principle of the electromagnetic heating of damp grain – first of all moisture in grain is heating up instead of grain itself. If to consider any other principles of drying, the most part of spent heat goes to heat up other part of grain body which is for biological reasons is absolutely not desirable.

Eventually, substituting in Maxwell's formula approximating coefficient of losses (σ) through humidity, we will receive engineering interpretation of the equation of Maxwell.

In the results of got dependence, amount of heat allocated from $1m^3$ of a material (Q), is possible to determine by a formula 6:

$$Q = 0.555 \times E^2 \times \omega \times (0.13 + 0.016W) \quad (6)$$

From here the third conclusion follows that we are the first who found Maxwell's' formula in engineering sense that suitable for calculating of heat discharged by grain moisture which depending on 3 parameters:

- Electromagnetically intensity;
- Radiation frequency;
- Self-humidity of grain.

The presented work is directed on research of distribution of an electromagnetic field of microwave range from several sources in a processed material.

Conclusions

Advantages of induction heating are given below.

Increased grain production in Kazakhstan is impossible without the development and improvement of grain storage technologies.

A method for drying grain and moisture removal, which is based on the receipt and processing of a thermal process is described by the equation of thermodynamics.

We tried grain drying by high frequency. When high-frequency drying heat is supplied via an electrical field ultra-high current (2000–2500 MHz) frequency, which is a consequence of Maxwell's theory, which states that «the higher the frequency of electromagnetic induction, the more heat is transferred to the heated body.»

The amount of heat (Q) is defined by Maxwell, meaning that drying of the grain depends on the strength, the dielectric properties of the medium, the frequency generator and the moisture content of grain.

This work aims to study the propagation of electromagnetic fields in the microwave range from several sources in the treated material.

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