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Computersimulation von Mikroklima in Lagerhallen für landwirtschaftliche Erzeugnisse

The POSOH software intended for optimum designing and operation of agricultural raw material storehouses on the basis of simulation of microclimate in biological production is submitted.

1 Introduction

Required current parameters of microclimate in storehouses depend on a plenty of factors. Many of these factors are variables. It is consequence of physiological changes of agricultural raw material in time and varying temperatures, specific humidity, air movement speed, air pressure and other parameters. Calculation of storehouses should be made on the basis of combined equations of a heat-and-mass transfer on the reference surfaces in elements of designs and in volumes of storage premises. In many cases it is possible to take into account all specificity only when allowing for non-stationarity and multiregularity of formation processes of temperature and moisture content parameters of biological medium during its evolution (BEUKEMA ET AL, 1982; DUNDAR ET AL., 1995; KLASSEN, 1993; KONDRASHOV, 1997).

Existent technologies of storage demand in each concrete case for processing and perfection on the basis of the analysis of thermal and moisture characteristics. On occasion given (optimum) equilibrium state of biological medium is analyzable with the help of mathematical simulation only. Development of exchange processes control and creations of the given microclimate is possible on this basis.

Most of researchers stated mathematical models in view of a lot of simplifications: unconjugacy of the thermal problem (the temperature of walling and covering is given and does not depend on a thermal state of a pile), (BERMAN & KALENDERIAN, 1986), one-dimensionality, stationarity (TASHTOUSH, 2000), disconnectedness of heat exchange and moisture exchange (JIA ET AL., 2000) etc.

The thermic and moist state of biological production which is taking place in storehouse, depends not only on thermodynamic processes in a pile, but also from exterior heat impacts through constructions of storehouses (especially it concerns a peripheral part of a pile), and also from the thermic perturbations added by equipment. Only the complete mathematical model of interrelated heat exchange based on the non-stationary conjugate problem of heat-and-moisture exchange for all system of design-equipment-pile in view of their thermal interrelation, instead of separately in each of areas participating in heat exchange (KONDRASHOV, 1997; KONDRASHOV, 2000), can take into account such features in their aggregate.

Mathematical statement of the complete problem includes combined equations: heat-and-mass transfer in a pile; heat conductivity for walling and covering in view of possible injection of outside air and emission of heat; energies in an air interlayer (KONDRASHOV, 2000). In the same our paper (KONDRASHOV, 2000) the method of their joint numerical solution is indicated under conditions of energy balance on contact surfaces, including in view of radiation.

Repeated experimental checkout of simulation results (KONDRASHOV, 1997; KONDRASHOV, 1999) has shown good concurrence of the real and calculated values - temperatures and specific humidity for various conditions and storage procedures of manifold fruit-and-vegetable production.

Enough complete and universal mathematical models are the most expedient to use as the basic part of software for application in practice of storehouses designing and the analysis of storage processes. So it is made in the POSOH software shown in this paper.

Application of known expensive commercial software packages on hydrodynamics and heat-and-mass transfer for simulation of controlled environment in storehouses is not effectively because they do not take into account specificity of processes in an organic production and essential conjugacy of the problem. Analogs of POSOH-type software for examination of storage processes are not known to us.

2 Functions and usage of the POSOH

The POSOH allows the designer selection geometrical and thermal parameters of walling and covering and parameters of the equipment operation on the basis of the calculated values of temperatures and moisture content by computing experiment, providing required temperature and humidity conditions (controlled environment) for all period of maintenance of storage depending on climatic zone and sort of stored production.

The POSOH can simulate processes for various types of storages, storage periods (winter, summer) and ventilation modes (natural and forced convection).

The complete mathematical model of interdependent heat-and-mass transmission on the basis of which calculation will be carried out allows exploring the dynamics of heat-and-mass transfer processes in storage for any time interval taking into account of exterior heat impacts most adequately (KONDRASHOV, 1997; KONDRASHOV, 2000).

The POSOH allows experts in maintenance of storages prediction controlled environment in storage under temperature and moisture content of surrounding environment (initial conditions for simulation) dependence. The POSOH allows to simulate various supernumerary situations during maintenance of storage and to pick those values of equipment parameters, which will provide way out from such situation in view of the least losses.Simulation of various situations is achieved by variation of the following performances:

- Ambient temperature;
- Temperature and relative humidity of ventilating air at the entrance point of the pile;
- The flux rate of ventilating air on 1 ton of stored production;
- Temperature of air in the upper zone of storage;
- Specific power of heat radiant for heating the upper zone;
- Some other performances depending on type of storage, mode of fanning etc.
- The POSOH fulfils the following functions:
- Input and editing of input data;
- Calculation of temperature and moisture fields in storage (initial conditions are given by the user);
- Graphics representation of temperature and moisture fields for a present situation of model time during calculation;
- Saving of calculation outcomes for the given moments of model time in manifold tabular and graphic forms;
- Prolongation of simulation after modification of input data (outcomes of simulation of prior time period are used as new initial conditions).

3 Solved problems

Processes in storehouse can be divided into the following groups:

- Biological processes in a pile of stored production;
- Heat-and-mass exchange of production and ventilating air;
- The processes caused by influence of environment.
- The following phenomena are examined in the POSOH from the point of view of these processes simulation:
- Breathing of stored products elements (self-heating of products);
- Transpiration cooling of production by ventilating air;
- Radiant heat exchange between top layer of production and surface of covering;
- Convective heat exchange between environment and surfaces of walling and cowering including seepage of air through the slots available in walling and covering of storage;
- Heat transfer through walling and covering by means of thermal conduction;
- Radiant heat exchange between the walling and the screen separating production from external walls.

All simulated processes are interdependent and non-stationary. It is taken into account completely during simulation (Kondrashov, 2000).

As a rule, two storage techniques are used at storage of juicy agricultural raw material: storage in pile and storage in containers. The POSOH allows simulation both pile and container storage.

Production is stored in ground or subsurface (semideepened) storages. Designed models for these storages have essential distinctions, though the general mathematical model is the same.

Storages are made in two types – with active and natural ventilation. The POSOH allows simulations of various modes of ventilation, namely:

- Continuous fanning of production with the small ventilating air consumption;
- Periodic fanning of production with the big ventilating air consumption.
- Two storage procedures are the most long and characteristic for all sorts of stored production:
- Cooling of production down to optimum temperature for storage;
- Actually storing.

For simulation of cooling mode it is necessary to set initial temperature of packed for storage production and resulting temperature, which is the storage temperature. The "Cooling" mode is realized in the POSOH as follows: after cooling production down to temperature of ventilating air the temperature of ventilating air automatically decreases (for example, on 3 K). Cooling of production is considered completed and calculation stops when temperature of production has lowering down to the storing temperature.

The environment influences, first of all, peripheral production layers – side and top. Therefore there is a necessity of a thermal shielding of peripherical layers of production. Air-thermal protection of storehouses is realized in the separate mode, namely:

- The air interlayer is used for protection of side layers. Air with the given temperature moves with the certain speed in the interlayer for reduction of environment influence;
- Sources of heat are used for protection of production top layers. They warm up a surface of a covering, thus reducing adverse for production radiant heat exchange of its top layers with a surface of a covering.

Calculation will be carried out for all parts of a construction, and conservation of energy conditions are used on mediums boundaries.

The ground storage with an aerated air interlayer (Fig. 1) from the point of view of processes simulation in it is the most general case and the mathematical model of these processes for the given type of storages is general for all types of storages viewed in the POSOH.

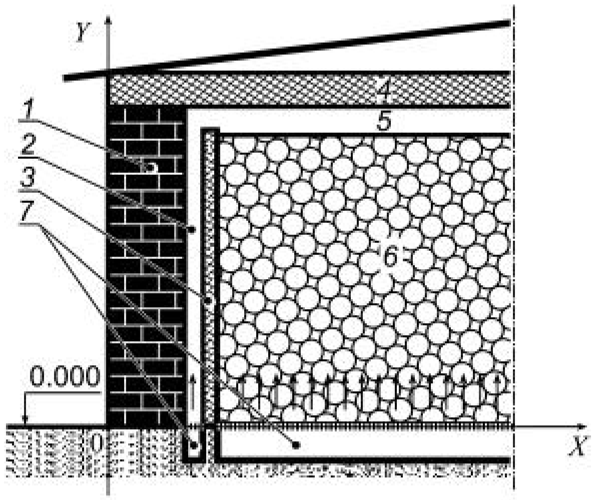

Fig. 1: The scheme of a ground storehouse with an aerated air interlayer: 1 – external wall, 2 – aerated air interlayer, 3 – separating screen, 4 – covering, 5 – top zone, 6 – pile of stored production, 7 – air ducts

The same mathematical model is applied for subsurface storehouses. Difference from storehouse with an aerated air interlayer is that heat exchange not with an environment, but with a soil is considered for subsurface part of the storehouse. Besides storehouses of such type have no an air interlayer.

For container storehouses the mathematical model does not vary, but the lateral is considered for this type of storehouses instead of the air interlayer.

4 Simulation by the POSOH

The general boundary value problem is solved in the POSOH under the locally-one-dimensional method under the implicit difference scheme. On the basis of a great many of the carried out computing experiments it is possible to state that the chosen method is practically steady against a choice of an amount of a grid steps on both coordinates and also to value of a time step.

Preparation of input data in the POSOH carried out interactively. The POSOH gives possibility to select sort and thermal characteristics of stored production from the inbuilt quick reference (Fig. 2) or to enter them independently.

Fig. 2. The input form for sort and thermal characteristics of stored production

Depending on selected type of storage access to input and editing of thermal, design and operation parameters, and characteristic for selected type is provided. The set of input data includes characteristics of materials of walling and covering (their heat capacity, density, and heat conductivity), radiant and convective heat exchange coefficients, speed and temperature of ventilating air etc.

The most general type is the storage with an air interlayer. During selecting of temperature of air on the entrance point in the air interlayer it is necessary to recognize that it is necessary to bring enough heat to exterior walling and covering on the one hand, and it is necessary do not admit excessive heating of bottom layers of stored products with another hand.

The temperature of soil at the underground part and the factor of heat exchange between soil and the underground part of the wall are set in case of a subsurface storehouse.

The set of container storage parameters essentially differs, as the container represents some volume of production with air canals on each side.

The set of geometrical parameters of a storage is various for different types of storages.

To calculate walling and covering on heat fastness it is necessary to set the daily average ambient temperature and the amplitude of the ambient temperature change during a day. With these values it is possible to simulate change of walling and covering temperatures under harmonic oscillations in the outdoor temperature.

At the simulation of the “Cooling” mode specify initial temperature of packed for storage production and the storage temperature. At cooling potatoes these temperatures as a rule are equal accordingly 291 K and 276 K. For the "Storage" mode two values are set also: minimum and maximum tolerant temperatures of production.

The coefficient of convective heat exchange between production and air essentially influences results of temperatures calculation (TASHTOUSH, 2000; KONDRASHOV, 2000).

The values directly influential in a controlled environment in a pile also are:

- The temperature of ventilating air at an entrance point in a pile. Usually this temperature is 3 – 4 K lower, than the temperature of production;
- The air flux rate in a pile. For example, for continuous ventilation of potatoes at pile storage it is recommended to set the air flux rate equal to 10 – 15 m3×t-1×h-1 (2.8×10-6 – 4.2×10-6 m3×kg-1×s-1), and for intermittent mode – 100 – 350 m3×t-1×h-1 (2.8×10-5 – 9.7×10-5 m3×kg-1×s-1).
- The relative humidity of air fed to the pile;
- The ambient temperature. It is set seasonally and on region, for which simulation will be carried out;
- The temperature of the top zone;
- The specific capacity of heat sources in the top zone.

The representation of entry conditions does not influence a final output as the problem of temperatures and humidity calculation is solved for enough big time intervals. Nevertheless, for acceleration of calculation it is desirable to set initial conditions similar to real ones for all considered zones of the storehouse and to take into account their

interdependence from each other and also from parameters of an environment.
Choosing the duration of the modeled time interval it is necessary to start with the following reasons:

- As experiments show, the steady conditions in storehouse under a cooling mode set in after 200 – 250 hours of model time;
- It is possible to stop calculation and then to continue it, and outcomes of the completed calculation become entry conditions for its prolongation.
- The POSOH has following forms of graphics representation of calculation results with which it is possible to work during calculation and after it completing:
- Isotherms;
- Isolines of a humidity content;
- Graphs of temperature in a selected zone dependence from coordinates X and Y;
- Graphs of relative humidity in the pile dependence from both coordinates;
- Graphs of humidity content dependence from both coordinates.

There are two more forms of the outcomes representation giving the most visual representation about the processes happening in a pile.

The temperature of various sites of a stored production pile is evidently represented in the form of temperature zones diagram. The POSOH allocates three kinds of temperature zones:

- Supercooling;
- Normal storage;
- Superheat.

Results of air relative humidity calculation in a pile are visually represented as the chart of condensation moisture fallout zones. Zones of a pile are considered as zones of condensation moisture fallout if the relative humidity of air in ones exceeds 100 %.

5 The simulation example

As the elementary example we shall consider simulation of potatoes storing in storehouse with an aerated air interlayer. Basic input data are shown in screen shots (Fig. 2, 3).

Fig. 3. The input form for thermal characteristics of storehouse with an aerated air interlayer

The chart of temperature zones in the pile of stored products (Fig. 4) visually shows that storing of potatoes in such conditions results in supercooling the wall part of the pile and in step-by-step self-heating of its central part. Air in the pile is moisture-laden. During moving from warmer regions of the pile to colder ones air gets cold and the moisture from it is condensed. It is well visible on the chart of condensation moisture fallout zones (Fig. 5).

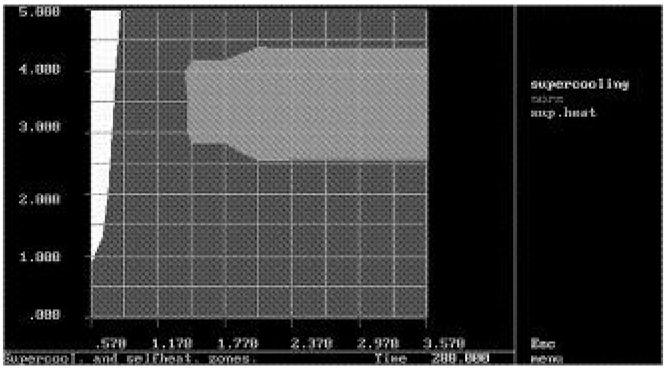

Fig. 4. The chart of temperature zones in a pile

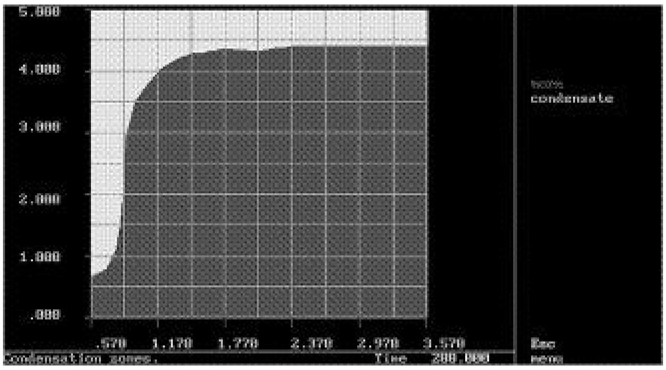

Fig. 5. The chart of condensation moisture fallout zones

By means of the further simulation it is possible to clarify, whether it will be possible to stop a self-heating of the internal part of the pile by means of more intensive fanning. For this purpose we shall stop calculation. We shall increase air flux rate in the pile from 10 up to 15 m3×t-1×h-1 (from 2.8×10-6 to 4.2×10-6 m3×kg-1×s-1), and then we shall continue simulation. Results (Fig. 6, 7) show, that such change of storage conditions eliminates superheat of the internal part of the pile and stops fallout of condensation moisture in its upper part. We shall remark, that in this case the increase of outtake air flux rate in the pile has not protected its wall part from supercooling. It is possible to exclude such overcooling due to change of an interlayer functioning mode, increase of thermal resistance of walling and covering or separating screen.

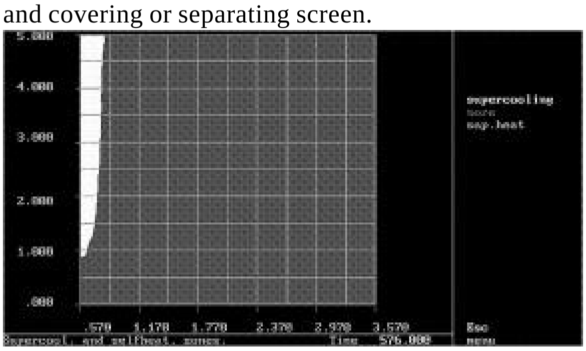

Fig. 6. The chart of temperature zones in the pile after the increasing of ventilating air flux rate

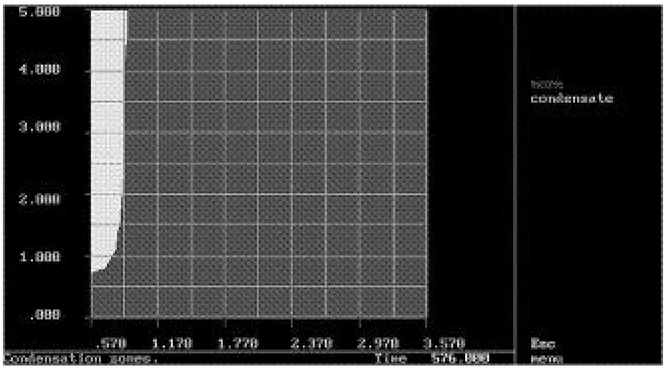

Fig. 7. The chart of condensation moisture fallout zones after the increasing of ventilating air flux rate

6 Conclusions

Thus, the specialized POSOH software submitted in this paper allows designers and operating staff of agricultural raw material storehouses using computer simulation of heat-and-mass transfer processes in their operation. It will allows estimating of the efficiency of the accepted designer solutions or selected operating conditions of the equipment for maintenance of optimal controlled environment in various types of storehouses in any storage period by realization of computing experiments.

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Computersimulation von Mikroklima in Lagerhallen für landwirtschaftliche Erzeugnisse (V.I. Kondrashov, N. Kondraschov, J.A. Kokin und V.M. Tyukov)

Zusammenfassung

Temperatur und Feuchtigkeit im Lagerhaus und in den eingelagerten Produkten sind entscheidende Faktoren, die den Lagerungserfolg von landwirtschaftlichen Erzeugnissen beeinflussen können.
Die Software POSOH errechnet für Sie, optimale Lagerungsbedingungen aus, um eine neue Lagerhalle entwerfen zu können. Bereits bestehende Lagerhallen können mit Hilfe von POSOH optimal ausgenutzt werden. Entstehende Produktionsverluste bei der Einlagerung werden minimiert.
POSOH simuliert die Lagerungsprozesse unter Berücksichtigung konstruktiver Besonderheiten Ihres Lagers (z. B. Be- und Entlüftung, Klimatisierung und Fassungsvermögen), Art der eingelagerten (einzulagernden) Produkten und deren Umweltbedingungen.

Stichworte: *Computersimulation, Mikroklima, Lagerhallen für landwirtschaftliche Erzeugnisse.*

Computer Simulation of Microclimate in Storehouses of Juicy Agricultural Raw Material (V.I. Kondrashov, N. Kondraschov, J.A. Kokin and V.M. Tyukov)

Summary

The temperature and the humidity in storehouse and stored production are determinatives for successful storage of agricultural production.
The POSOH software allows calculating optimum storage conditions during designing new storehouses. The POSOH will help to maintain already constructed storehouses in the best way. Losses of production when storing will be reduced considerably.
The POSOH simulates storing processes considering design features of your storehouses (for example, changes of aeration, cooling, volume and so on), a kind of a stowed product and environment.

Key words: *computer simulation, microclimate, storehouse of agricultural raw material.*

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