MODELLING THE ENERGY EXCHANGE IN A FOOD STORAGE REFRIGERATED CHAMBER

Nadezhda EVSTATIEVA[1]
Georgi GEORGIEV[2]
Nikola MIHAILOV[3]
[1] Assoc.Prof., PhD, Department of Theoretical and Measuring Electrical Engineering, Faculty of Electrical and Electronic Engineering and Automation, University of Ruse, Bulgaria
[2] Assoc. Prof., PhD, Department of Theoretical and Measuring Electrical Engineering, Faculty of Electrical and Electronic Engineering and Automation, University of Ruse, Bulgaria
[3] Prof., PhD, Department of Electrical Power Engineering, University of Ruse, Bulgaria

Abstract: *The food storage refrigerated chambers are widely used in the food industry. During their operation it is very important to comply with the technology regime requirements, i.e. maintaining the required temperature of the stored in the chamber products. The operation specifics of a food storage refrigerated chamber have been analyzed. The necessity for a temperature estimation of the stored products in the chamber during loading and unloading has been substantiated. The main approximations and dependencies during the process modeling have been grounded. A model of the energy exchange in a food storage refrigerated chamber has been suggested, allowing to simulate the kinetic curves of the products temperature. The model could be used to control the temperature regime of the stored production by means of an electronic system*
Key-words: *food storage refrigerated chambers, model, energy exchange.*

1. INTRODUCTION

The refrigeration chambers are widely used in the food industry. During their operation it is very important to comply with the technology regime requirements, i.e. maintaining the required temperature of the stored in the chamber products. During normal exploitation, the aggregates maintain the required temperature in the chamber. But when the regime includes loading and unloading the chamber doors are opened for certain periods of time, which leads to heat exchange between the refrigerated chamber and the environment. This leads to increase in the stored products temperature [4, 6]. In order to escape deviation from the technological requirements, it is important to know the product temperature and the maximum time interval for loading and unloading. In [3] have been modeled the processes in a chamber for agricultural products storing. But this model does not describe the process during loading and unloading when the chamber doors are opened.

The aim of this research is to develop a model, describing the energy exchange in a refrigerated chamber, which could be used to control the temperature regime of the stored production by means of an electronic system.

2. OBJECT OF THE INVESTIGATION

Structure of a refrigerated chamber is shown on Fig.1. The refrigeration chamber is a volume, enclosed by walls with insulation (1) with door (2) and a refrigeration unit (3). The stored products (4) are positioned in the chamber volume.

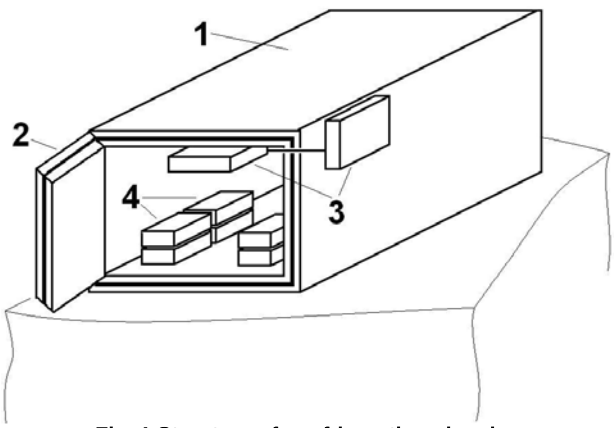

Fig. 1 Structure of a refrigeration chamber
1 – body of the refrigerated chamber; 2 – door; 3 – refrigeration unit; 4 – stored products.

3. JUSTIFICATION OF THE APPLIED APPROXIMATIONS AND DEPENDENCES

The modeling is based on the finite differences method [1, 2]. According to it the time and space is divided into very small intervals. It is assumed that for the very small time interval $\Delta\tau$ the values of the parameters are constant.

In order to model the heat exchange through the refrigeration chamber walls it is assumed that the heat is exchanged through a specific flat wall. The chamber and the specific flat wall have the same surface, width and insulation performance.

It is assumed that the heat exchange between the walls and the environment, as well as between the walls and the air in the chamber is convective. The heat exchange coefficient is determined according to [5]:

$$\alpha = 5{,}6 + 4.v \text{ , } W.m^{-2}.K^{-1} \text{,} \tag{1}$$

where v is the air velocity, $m.s^{-1}$.

The convective heat exchange is evaluated according to [1]:

$$N_{CH} = \alpha.\Delta t.F \text{ , } W \text{,} \tag{2}$$

where Δt is the temperature gradient between the walls and air, K;

F - the walls surface, m^2.

In order to describe the energy exchange through the walls the dependency for heat exchange through a flat wall. The heat power is defined by the formula [1, 6]:

$$N_H = \frac{\lambda}{\delta}\Delta t.F \text{ , } W \text{ ,} \quad (3)$$

where λ is the heat conductivity of the wall, $W.m^{-1}.K^{-1}$;

δ - the width of the wall, m.

It is assumed that the stored products have the same temperature in the whole volume.

In order to model the loading and unloading process it is assumed that while the door is open the air is exchanged for time interval τ_{EX}. The volumetric debit of the incoming environment air is calculated according to:

$$v_{VOL} = \frac{V_{CH}}{\tau_{EX}} \text{ , } m^3.s^{-1} \text{ ,} \quad (4)$$

where V_{CH} is the volume of the refrigerated chamber, m^3.

When environment air enters the refrigerated chamber it is assumed it mixes with the chamber air. The inertia heating process is described with a calorimetric equation [1, 6]:

$$Q = m.c.(t_2 - t_1) \text{ , } J \text{ ,} \quad (5)$$

where Q is the added energy, J;

m - the mass of the products, kg;

c - the specific heat capacity of the products, $J.kg^{-1}.K^{-1}$;

t_1, t_2 - the products temperature before and after the energy is added, ^oC.

It is assumed that the specific heat capacity of the environment and of the air in the chamber are equal.

4. PROCESS MODELLING

The algorithm of the model of the energy exchange in a food storage refrigerated chamber is presented on Fig. 2.

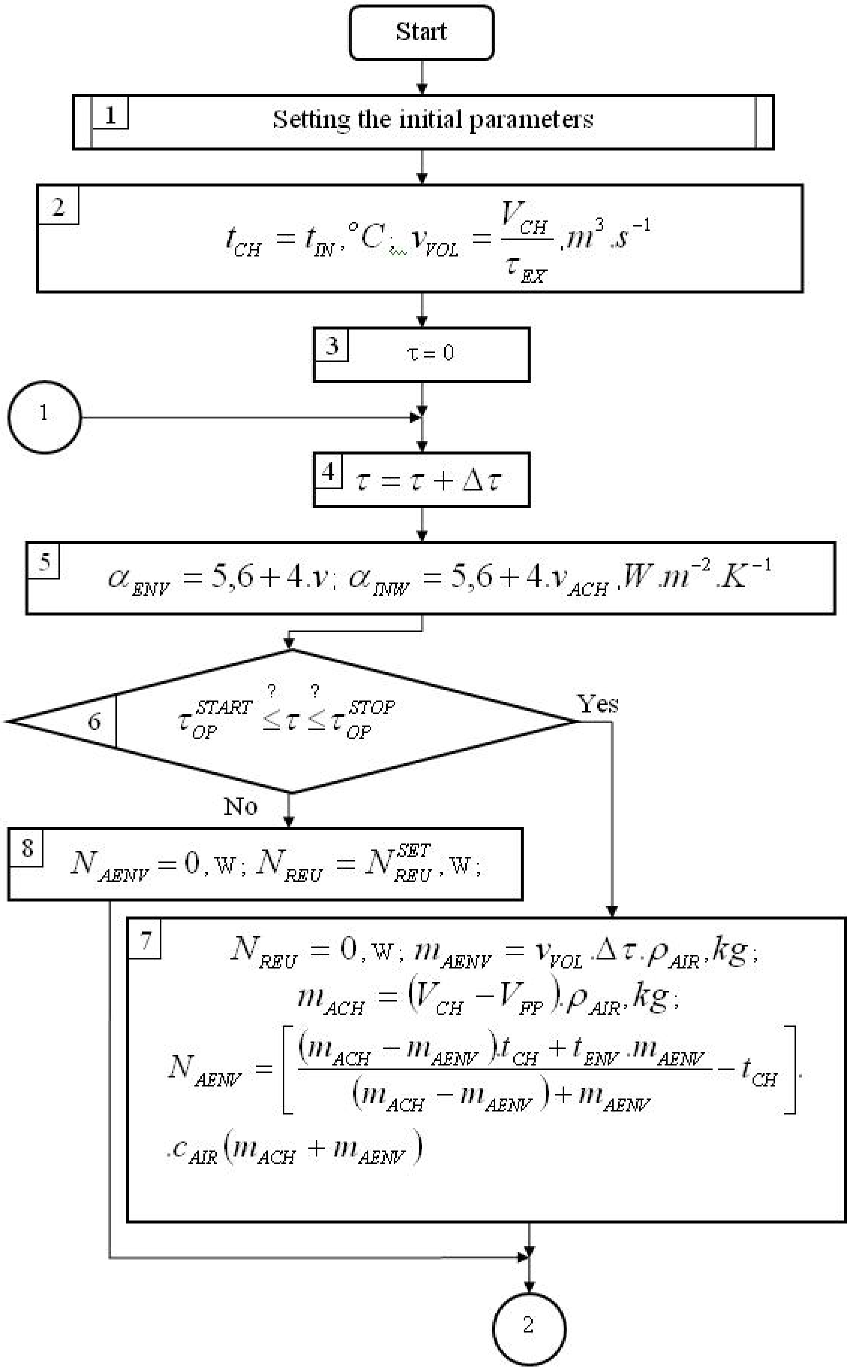

Fig. 2.a Algorithm of the energy exchange model in a food storage refrigerated chamber

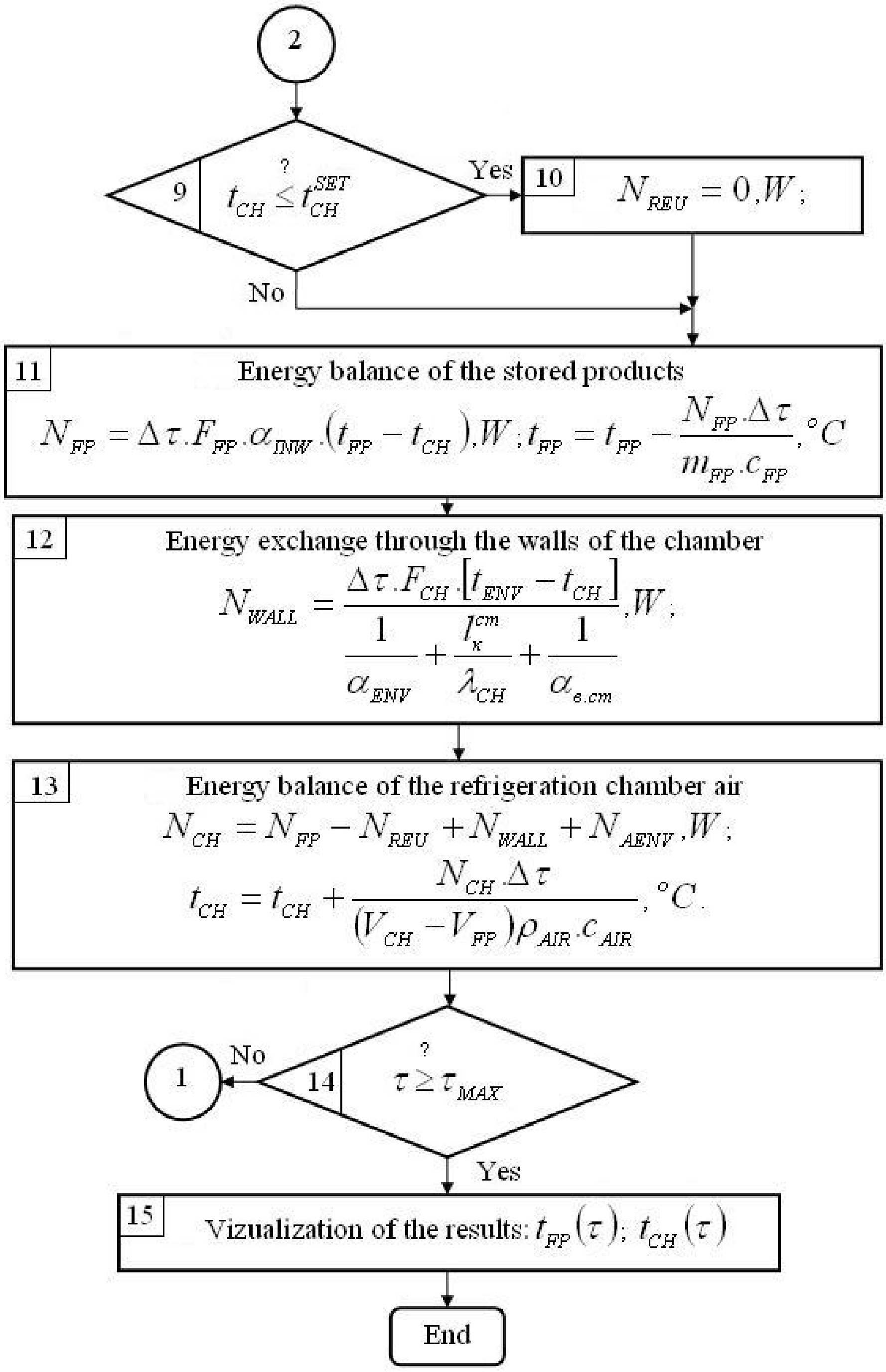

Fig. 2.b Algorithm of the energy exchange model in a food storage refrigerated chamber

The initial conditions are set in block 1. In block 2, the initial temperature is set and the volumetric debit of the incoming air when the door is opened is determined. In blocks 3, 4 and 14 the virtual time for the calculating process is organized. In block 5, the coefficients of convective heat exchange between the walls of the chamber and the environment and between the walls and the chamber volume are evaluated.

The simulation of the opened or closed door is carried out in blocks 6, 7 and 8. When the door is opened, it is assumed that the refrigeration unit is turned off and it doesn't add energy ($N_{REU} = 0$), in block 7. Then the masses of the mixed volumes of air and the additional energy entering the refrigeration chamber for a timer interval $\Delta\tau$ are evaluated. In block 8, the refrigeration unit is turned on ($N_{REU} = N_{REU}^{SET}$) and the volume amount coming from the environment is equal to zero ($N_{AENV} = 0$). In blocks 9 and 10, operation of the system for control of the refrigeration unit is simulated. After reaching the required temperature in the chamber, the energy added by the refrigeration unit is set to zero ($N_{REU} = 0$). The energy level variation of the stored food products is evaluated in block 11 and the energy exchange through the walls - in block 12. In block 13 the energy balance of the air in the chamber is calculated. In block 15 the information about the simulation process is visualized.

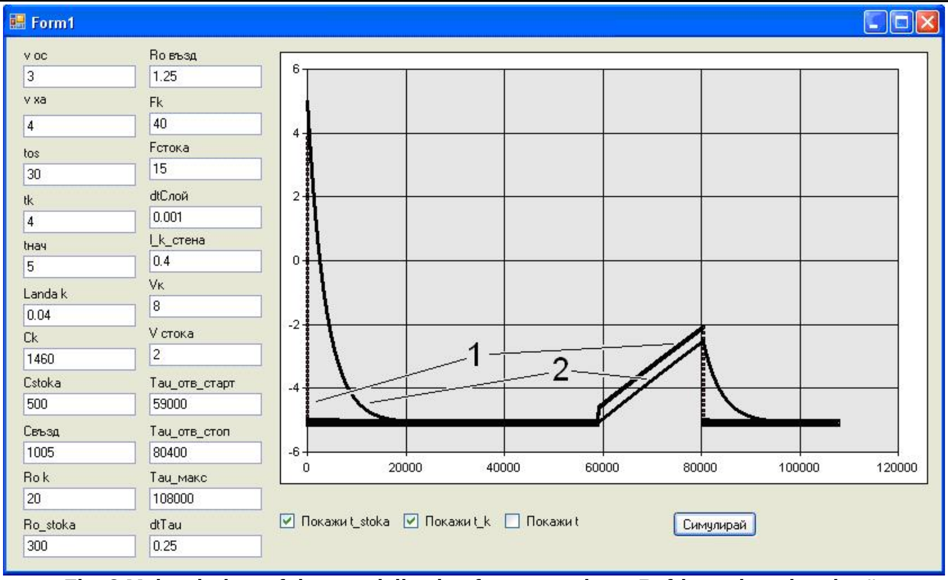

Fig. 3 Main window of the specialized software product „Refrigeration chamber":
1 – temperature of the air in the chamber; 2 – temperature of the stored food product.

A specialized software application has been developed in the Visual Studio 2010 environment, which implements the model of the energy exchange and allows to simulate the energy exchange in a refrigerated chamber. The main window of the product is shown on Fig. 3. It displays the temperature variation of the stored food products and of the air in the chamber.

The graph represents simulation of the chamber cooling after which between 60000 and 80000 s the door is opened.

5. RESULTS AND CONCLUSIONS

The operation specifics of a food storage refrigerated chamber has been analyzed. The necessity for a temperature estimation of the stored products in the camera during loading and unloading has been substantiated. The analysis shows that during prolonged loading and unloading the technological requirements for the production storing are violated. That is why it is necessary to evaluate the products temperature in the chamber in order to control it during prolonged loading and unloading procedures.

The main approximations applied in the process modeling have been grounded.

An algorithm describing the energy exchange in a food storage refrigerated chamber has been suggested, allowing to simulate the kinetic curves of the products temperature. The algorithm has been implemented in a specially developed software application "Refrigeration chamber" in order to simulate the energy exchange processes.

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