ARPN Journal of Engineering and Applied Sciences

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EVALUATION OF AIR DISTRIBUTION EFFICACY IN STORAGE FACILITIES FOR PERISHABLE PRODUCTS

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ABSTRACT

Evaluation method for air distribution efficacy in storage facilities for perishable products is provided. Parameters of air medium are considered as random variables. Statistical laws of their distribution are used in the study of ventilation processes. Calculation of air distribution is suggested to be performed by maximal permissible temperature state in the product stack.

Keywords: air distribution, storage of perishable products, porous layer structure, limit-probabilistic method.

INTRODUCTION

Microclimate of any facility is characterized both by mean values of physico-chemical parameters of the air medium and by their distribution in considering volume.

Randomness of pore channels shape and size in the stack and dry-placed fill of stored products in the storage facilities for perishable products leads to that the vector of local air flow rate significantly changes its value and direction even in neighboring points of flow [1]. Uneven distribution of air medium parameters is observed both in longitudinal and transverse directions. Artificial venting can make this event worse because of which structural lesions and significant contrast range of air medium physical parameters

The general property of such structural lesions is their stochastic nature [2]. In this case air medium parameters should be considered as random values and statistical laws of their distribution should be used in the study of ventilation processes [3]. Therefore the use of method for account of actually significant heterogeneity of empiric distribution (for example, temperature) is reasonable in comparison of air distribution variants and air exchange calculations because it extends abilities of analysis and generalization of experiment results.

MATERIALS AND METHODS

As a rule the efficacy of air distribution systems in perishable products storage is evaluated by exceeding of air temperature at stack exit ($\Delta t_{st}^{out} = t_{st}^{out} - t^{in}$), and its comparison with standardized value ($\Delta t_{st}^{stand} = t_{st}^{stand} - t^{in}$) from the case that $\Delta t_{st}^{out} \le \Delta t_{st}^{stand}$,

where

t_{st}^{out} - air temperature at stored products stack exit, ºC;

t^{in} - temperature of inflowing air, ºC;

t_{st}^{stand} - standardized air temperature in products stack, ºC.

The air flow that should be supplied in the facility loaded with products, G, kg/s, is determined from the case of maintaining of standardized temperature gradient in the layer of stored products

$$G = \frac{Q}{C_p \cdot \Delta t_{st}^{stand}}, \tag{1}$$

where Q - heat flow, W;

C_p - specific air heat capacity at constant pressure, J/(kg·K).

To calculate required volume of ventilation air and compare different air distribution systems in relation to facilities of industrial buildings unlike loaded facilities use temperature simplex $m_{\Delta t} = (t_{w.a} - t^{in})/(t^{out} - t^{in})$, where - $t_{w.a}$ air temperature in the working area, ºC; or the value of air exchange organization coefficient, C_e:

$$\frac{1}{m_{\Delta t}} = C_e. \tag{2}$$

Then:

$$G = \frac{m_{\Delta t} \cdot Q}{C_p \cdot \Delta t_{st}^{stand}}. \tag{3}$$

Based on experimental data it is established that value of $m_{\Delta t}$ depends on different factors: air flow and scheme of air exchange organization, heat power and size of heat sources, facility height, quantity of convective and radiant heat, etc. [4, 5]. Although most of known works in $m_{\Delta t}$ (C_e) value determination has especially experimental character and obtained results are applicable only for special cases [6]. Analytical method for determination of air exchange organization coefficient is based on development of mathematical models of heat-mass-exchange processes in the facility [7].

It was considered that it is necessary to aim for increase of air exchange organization coefficient as the

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more C_e value is the lower the required air exchange is, more rationally the inflow air is used [8]. In a whole the effect of C_e coefficient on air exchange system wasn't taken into account.

Although value of C_e coefficient ($m_{\Delta t}$) has effect both on air exchange and heat, cold consumption [9, 10]. Also it should be noted that it is impossible to consider about quality of air exchange organization by C_e value ($m_{\Delta t}$) in a strict sense because the heterogeneity of distribution field for test parameter is not taken into account.

Random values have an effect on Δt_{st}^{out} and $m_{\Delta t}$ in the stored product stack. Taking this into account in further we would consider that $m_{\Delta t}$ is temperature simplex which connects mean excessive air temperature in the product stack and mean excessive air temperature outflow from the facility. Thus for considering case we will have:

$$m_{\Delta t} = \frac{t_{st}^{m} - t^{in}}{\Delta t_{st}^{out} - t^{in}}. \tag{4}$$

At the same time it is proved [11, 12] that Δt^{out} and $m_{\Delta t}$ can't be considered to be the single criteria for ventilation evaluation. Additionally the analysis of test parameter field is required.

RESULTS AND DISCUSSIONS

At storage of packaged frozen products the main parameter which determines preservation is temperature of intrastack air. Therefore in this case it's necessary to reveal the character of its distribution in the products mass. Such statistical study will allow us to reflect both physical side of events: average level and structural scale of lesions in limited volume and resulting effect of engineering procedures: quality of air exchange organization.

As it is known the following is used most often to assess random distribution of any parameter "x" [3]:

mathematical expectation or mean value of "x" parameter;
range of variability R_x;
dispersion (diffusion) of sample value around mean σ_x^2;
mean square deviation σ_x;
variation coefficient or relative deviation parameter υ_x.

When initiating the analysis of filtration processes for intrastack air in the layer of stored products which didn't undergo detailed statistical assessment it is reasonable to continue it using Pearson's test – χ^2, which efficient to assess divergence between empiric and normal (theoretic) distribution [3]. If ranked empirical series x_i is divided into several intervals S equal to Δx length and 2 parameters are evaluated (x^m and σ_x), than number of degrees of freedom to determine the tabular (critical) value χ^2 is equal to K=S-1-2=S-3. Meanwhile significance level is accepted as $\alpha \geq 0, 05$. Null hypothesis can be accepted if observed (empiric) value $\chi^2_{obs.}$ will be lower than tabular one $\chi^2_{tab.}$ at K and α:

$$\chi^2_{obs.} < \chi^2_{tab.}(\alpha, K). \tag{5}$$

After review of hypothesis on normal law of air parameters distribution in ventilating volume the transfer to probabilistic analysis is accepted for temperature fields in stored products stack. For this purpose we will present distribution of "x" parameter in products stack (Figure-1) in the form of ranked series [11]. In Figure-1 borderline, standardized and mean value: x_{st}^{max}, x_{st}^{min}, x_{st}^{stand} and x_{st}^{m}, as well as parameters of inflow and outflow air x^{in} and x^{out} are marked on the X-axis. The excess of parameter over target level in products stack is designed as δ, inflow air - Δ.

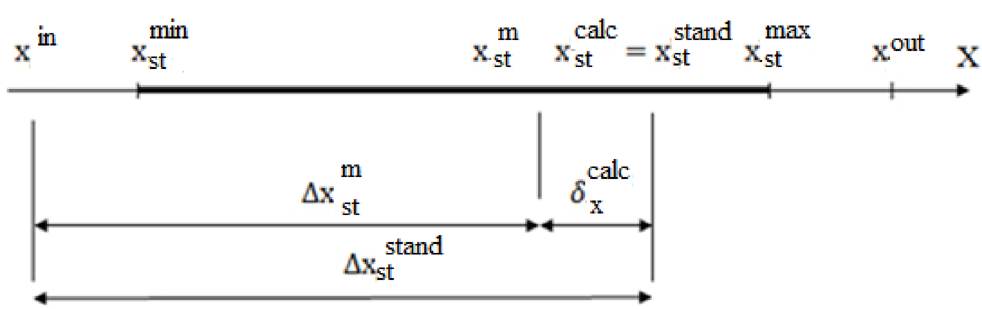

Figure-1. Scheme of "x" parameter distribution in products stack and in ventilating volume limits.

VOL. 13, NO. 10, MAY 2018 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

If parameter standardization is limited only by upper limit ($x_{st.i} \le x_{st}^{stand}$) like this occurs by temperature, for example, at storage of frozen fish products, its calculated value equal to x_{st}^{stand} should be as close as possible to x_{st}^{max}. Meanwhile an achievement of case $x_{st}^{max} = x_{st}^{stand}$ is almost difficult to do and unreasonable as the probability of appearance of significant deviations x_i from x^{in} is rather small and x_{st}^{max} is maximal value among measured but not existed values. It's more really to calculate:

$$x_{st}^{m} < x_{st}^{calc} = x_{st}^{stand} < x_{st}^{max}.$$

This ratio is the initial methodological basis of limit-probabilistic method for calculation of air exchange in contrast with common solution at which $x^{calc} = x^{m}$. The value of deviation x_{st}^{calc} from x_{st}^{m} - δ_x^{calc} is determined using parameters of field heterogeneity (σ_x) and standardization of argument χ. The latter is determined from normal law of its distribution taking into account that $\delta_x^{calc} = \chi \cdot \sigma_x$:

$$\chi = \frac{x_{st}^{calc} - x_{st}^{m}}{\sigma_x}. \quad (6)$$

The probability that numeric value of parameter "χ" is higher than target limit (x^{stand}) is evaluated using Laplace's function:

$$P(x > x^{stand}) = 0,5 - F(\chi), \quad (7)$$

$$F(\chi) = \frac{1}{\sqrt{2\pi}} \int_0^x e^{-x^2/2} d\chi. \quad (8)$$

It is evident that $F(-\chi) = -F(\chi)$; at $\chi=0$ $F(\chi)=0$, at $\chi=5$ $F(\chi)\approx 0,5$.

At accepted deviations of empiric distribution from normal level Laplace's function with replacement of standardized argument $\chi=\delta_x/\sigma_x$ to argument $z=f(\chi)$ also can be used for its description. The excess of "x" parameter in products stack in comparison with its standardized value (x_{st}^{stand}) can be set with certain probability P ($x_{st.i} > x_{st}^{stand}$)≤P* and values of standardized argument χ^* relevant to it can be established using empiric distribution (graphical plotting of normal law is presented in Figure-2).

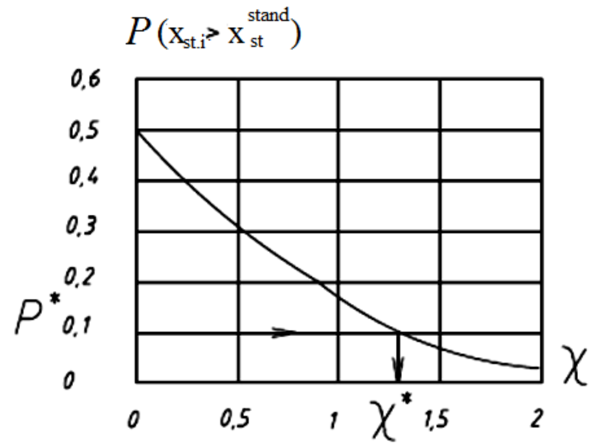

Figure-2. Graphic interpretation of dependence (7) at normal law of distribution of standardized argument in Figure.1 shows that.

$$x_{st}^{stand} = x_{st}^{m} + \delta_x^{calc}.$$

Taking into account that $\delta_x^{calc} = \chi^* \cdot \sigma_x$, we will have:

$$x_{st}^{stand} = x_{st}^{m} + \chi^* \cdot \sigma_x \quad (9)$$

Meanwhile both heterogeneity (by stack volume) and probabilistic law of distribution of interested parameter are taken into account.

We'll take from the right and left parts of equation (9) the value x^{in} when:

$$\Delta x_{st}^{stand} = \Delta x_{st}^{m}(1 + \chi^* \cdot \sigma_x / \Delta x_{st}^{m}) \quad (10)$$

In equation (10) the ratio of mean square deviation for random parameter "x" to mean excessive is "ventilation variation coefficient" [11]:

$$\bar{\sigma}_x = \frac{\sigma_x}{\Delta x_{st}^{m}}. \quad (11)$$

In accordance with above we can transfer to the method of substantiated determination of calculated air exchange at storage of perishable products taking into account actual heterogeneity of temperature field in products stack.

Mean excessive temperature Δt_{st}^{m} can be expressed through Δt^{out} and simplex $m_{\Delta t}$:

$$\Delta t_{st}^{m} = m_{\Delta t} \cdot \Delta t^{out} \quad (12)$$

From other side taking into account (10)

$$\Delta t_{st}^{m} = \Delta t_{st}^{s\tan d} / (1 + \chi^{*} \cdot \sigma_{\Delta t}) \tag{13}$$

Solving jointly (12) and (13) in relation to Δt^{out} we will have:

$$\Delta t^{out} = \frac{\Delta t_{st}^{s\tan d}}{m_{\Delta t}(1 + \chi^{*} \cdot \overline{\sigma}_{\Delta t})}. \tag{14}$$

The value of Δt^{out} is calculated from equation of heat balance:

$$\Delta t^{out} = \frac{Q}{G \cdot C_p}. \tag{15}$$

Then from (14) and (15) calculated air exchange is equal to:

$$G = \frac{m_{\Delta t} \cdot Q \cdot (1 + \chi^{*} \cdot \overline{\sigma}_{\Delta t})}{C_p \cdot \Delta t_{st}^{s\tan d}}. \tag{16}$$

Thus calculation of air exchange by maximum permissible temperature state in frozen products stack guarantees with target reliability χ^{*}, that $t_{st} \leq t_{st}^{s\tan d}$. Analyzing equation (16), it can be noted that taking into account heterogeneity of air exchange temperature fields determined from the case that $\Delta t_{st}^{m} < \Delta t^{s\tan d} < \Delta t_{st}^{max}$, is higher than in the case of $\Delta t_{st}^{s\tan d} = \Delta t_{st}^{m}$.

The term of efficacy coefficient is entered as characteristics of air distribution system [13, 14]:

$$C_{ef} = \frac{1}{m_{\Delta t}(1 + \chi^{*} \cdot \overline{\sigma}_{\Delta t})}. \tag{17}$$

It can be considered that efficacy coefficient includes reliability characteristics (1-P($x_{st.i} > x_{st}^{s\tan d}$)) as χ^{*} corresponds to certain probability of $x_{st.i}$ exceeding over $x_{st}^{s\tan d}$. At this the value $1/1 + \chi^{*} \cdot \overline{\sigma}_{\Delta t}$ is quality coefficient:

$$C_{qual} = \frac{1}{1 + \chi^{*} \cdot \overline{\sigma}_{\Delta t}} \leq 1. \tag{18}$$

The latter is explained by that the quality and efficacy should be interdependent

$$C_{ef} = \frac{C_{qual}}{m_{\Delta t}}. \tag{19}$$

CONCLUSIONS

a) The method of determination of air exchange taking into account air distribution efficacy in storage facilities for perishable products is developed.

b) Parameters of air medium are considered as random values. Statistical laws of their distribution are used in the study of ventilation processes.

c) Calculation of air distribution is suggested to be performed by maximal permissible temperature state in the product stack with target reliability.

d) To compare variant solutions of air distribution at target guarantees for calculation quality and efficacy coefficients (C_{ef} and C_{qual}) can be used as objective parameters. In accordance with physical content they reflect imperfection degree of actual way of air distribution versus "ideal" one.

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