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MECHANICS

O. Lanchava

Separation and Evaluation of Simultaneous Heat-Mass Exchange in Binary Systems

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ABSTRACT. **A new criterion for separation and evaluation of simultaneous heat and mass exchange process obtained on the basis of tertiary boundary condition analysis is introduced using я-theory and L'Hospital's rule. The numerical value of the criterion shows whether consideration of additional heat flow during simultaneous heat-mass exchange is necessary or not. © 2005 Bull. Georg. Acad. Sci.**

Key words: heat mass exchange, air flow, mass emission, heat emission, exchange potential.

During ventilation of underground constructions, aerodynamical, thermal and mass boundary layers arise on the side of the moving component of a "mountain range - air flow" binary system and stabilizes by time. The airflow disturbs natural heat and mass exchange fields in an open mountain range causing cooling and drying of layers of the binary system heat mass exchange takes place through. Their thickness and, respectively, the transferred mass and energy values become stabile. The goal of this work is to evaluate these processes for thermalphysic estimation of constructions. It requires separating the processes and introducing some simplifying assumptions.

Let us assume that mountain massif is characterized by temperature and mass transmission potential force fields, kinetic coefficients describing the environment do not change by time within the range of temperature and potential variations and also the current temperature, mass exchange potential and relative humidity are invariable. In such conditions, the mutual heat mass exchange can be described by Luitov-Mikhailov's differential equation system [1].

In order to obtain unambiguous solution of this system, it is necessary to meet tertiary boundary conditions on the interface of the binary system:

$$-\lambda\frac{\partial t}{\partial R} + \alpha(t_1 - t_2) + a_m r(\theta_1 - \theta_2)=0, \qquad (1)$$

where λ is the heat conductivity coefficient of the massif (W/ M.deg.); t, t_1, t_2, - temperatures of the body, the passageway walls and the air respectively (°C); α - heat emission factor (W/ m2.deg.), α_m - mass emission factor (kg.kmol/kJ.m^2.sec), r - specific heat of the phase change (kJ/kg); θ_1 - mass transmission potential of the wall (kJ/kmol), θ_2 - mass transmission potential of the air (kJj/kmol); R - cylindrical coordinate (m).

Equation (1) is an expression of the energy conservation law for the mentioned system. To analyze it, application of a new similarity criterion is needed. According to 7i-theorem, similarity criterions for dimensional, primary dimensional and dimensionless quantities in this equation are 9,5 and 4 respectively [2]. These criterions are dimensionless temperature, bio- and mass transmission Posnov complexes:

$$\frac{\Delta_\tau t}{\Delta_R t} = t_{(R,\tau)} = \frac{t - t_2}{t_0 - t_2}, \quad Bi = \frac{\alpha R_0}{\lambda}, \quad Pn_m = \delta_\theta \frac{\Delta t}{\Delta \theta}, \tag{2}$$

where τ is time (sec.); t_0 - natural temperature of undisturbed mountain massif (°C); R_0 - equivalent radius of the passageway (m.); δθ - thermal gradient factor in the mass transmission potential scale showing additional mass transmission in the system in the form of Soret effect (kJ/kmol.deg.); Δt, ΔQ - temperature and potential increments respectively. The rest of the symbols were determined previously.

After insertion of limited proportional quantities according to L'Hospital's rule and multiplication by $R/\lambda\Delta_\tau t$, equation (1) will transform as:

$$\frac{\Delta_\tau t}{\Delta_R t} = \frac{\alpha R}{\lambda} + \frac{\alpha_m r R}{\lambda} \frac{\Delta_\tau \theta}{\Delta_\tau t} \tag{3}$$

For the passageway wall, i. e. when $R=R_0$ after simple transformations equation (3) will get the following form:

$$\frac{\Delta_\tau t}{\Delta_{R_0} t} = Bi + La \frac{Bi}{Pn_m}, \tag{4}$$

where a new criterion

$$L_a = \frac{\delta_\theta a_m r}{a} \tag{5}$$

is introduced. As it is seen from equation (4), dimensionless temperature of a passageway wall is combination of the appointed complexes. Thus, criterion expressed by formula (5) is the very fourth dimensionless complex that is necessary for the process analysis according to π-theorem.

The new criterion is a synthesis of Lewis, Kosovich and Posnov criteria. To prove it, let us consider heat and mass densities on the binary system interface according to the basic Fourier conduction law and Newton-Rikhman law, which are expressed as:

$$\alpha(t_1 - t_2) = -\lambda \mathrm{grad}\, t, \quad \alpha(\theta_1 - \theta_2) = -\lambda \mathrm{grad}\, \theta \tag{6}$$

respectively. In addition to already defined values there is a new one - λ_m denoting mass conductivity factor of the massif(kg·kmol/kJj·m·sec).

The basic relations of heat and mass physical characteristics of rocks are [3,4]:

$$\lambda = \alpha c \gamma_0, \qquad \lambda_m = \alpha_m c_m \gamma_0, \qquad (7)$$

where α is heat conductivity factor of the rock and α_m, - mass transmission potential conductivity factor (m^2/sec.); c - specific heat (kJj/kg.deg.); c_m - specific isothermal mass capacity (kmol/kJ); γ_0- the rock density (kg/m^3). Using simple transformations and considering (7) and (6) we get:

$$\alpha = -ac\gamma_0 \frac{\Delta_r t}{\Delta_{R_0} t}, \quad \alpha_m = -a_m c_m \gamma_0 \frac{\Delta_r \theta}{\Delta_{R_0} \theta}. \qquad (8)$$

Taking into account expressions of Lewis and Kosovich criteria, which are

$$\mathrm{Le} = \frac{a_m}{a}, \qquad \mathrm{Ko} = \frac{rc_m}{c}\frac{\Delta\theta}{\Delta t} \qquad (9)$$

respectively and inserting equati6n (8) in (5), after simple transformations we get:

$$\mathrm{La} = \mathrm{LeKoPn}_m \qquad (10)$$

that is the proof of our suggestion.

The new criterion relates thermal resistance $1/\alpha$ with mass transmission analogical resistance $1/\alpha_m$ within the limits of corresponding boundary layers. Thus, estimation of a ventilation air flow by it appears to be possible as both of those values are the current characteristics.

The first impression is that the same result can be obtained by Lewis, Kosovitch, or Posnov criteria separately. This is not quite correct as each of them taken separately characterizes just the massif showing only a rate of increase of cooled and dried up layers thicknesses.

The mentioned rate for a layer is what Lewis criterion shows in its classical form. Coefficient a shows temperature exchange rate in a massif caused by distortion introduced by an air flow energy impulse. Analogically, α_m is an indicator of potential exchange rate. It is impossible, to estimate air flow parameters by relation between them. Such estimation was done in [5] wrongly assuming that $\sqrt{a/a_m} = 1$, based on a pointed out in [1] statement considering that if Le=1, then the thicknesses of the heat and body boundary layers are equal and the heat and the mass transmissions are identical. This statement is formally correct, but in reality, it is wrong as appointed coefficients for the same layer differ from each other at least by two degrees [4]. Moreover, neither Kosocvitch, nor Posnov criteria allow the correct thermophysical calculation of air flow as it requires knowledge of the desired quantities such as flow temperature and potential in advance. The point is that temperature and potential increments in the first approximation are $\Delta t = t_1 - t_2$ and $\Delta\theta = \theta_1 - \theta_2$, where t_2 and θ_2 are the desired values.

In fact, temperature gradient always causes additional mass flow and vise versa - potential gradient causes additional thermal current, but there are cases in practice, when consideration of these additional currents is not necessary for calculation of flow temperature, mass transfer potential and relative humidity. The said is corroborated by the critical value of the new criterion $10^6 L\alpha = l$. Consideration of interference of these two processes for solution of multiparametric tasks is needed when this equality fails.

In any case, dimentionless temperature by solution of the afore mentioned Luitov-Mikhailov's differential equations has the following form:

$$t_{(\tau, R_0)} = Bi(1 + LaPn_m^{-1}). \qquad (11)$$

This equation makes it possible to determine nonstationary heat transmission factor considering an additional heat flow or without it.

As a result, it may be concluded that separation and evaluation of simultaneous heat mass exchange processes using the criterion introduced in this paper is possible.

Georgian Academy of Sciences

G. Tsulukidze Mining Institute

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ო. ლანჩავა

ერთობლივი თბომასაგადაცემის პროცესების გამიჯვნა და შეფასება ბინარულ სისტემებში

რეზიუმე. ბინარულ სისტემებში ერთობლივი თბომასაგადაცემის პროცესების გამიჯვნისა და შეფასების მიზნით შემოტანილია ახალი კრიტერიუმი, რომელიც მიღებულია მესამე რიგის სასაზღვრო პირობის ანალიზის გზით - π-თეპრემისა და ლოპიტალის წესის გამოყენებით. ახალი კრიტერიუმის კრიტიკული რიცხვითი სიდიდე უჩვენებს იმ შემთხვევებს, როცა ერთობლივი თბომასაგადაცემისას აღძრული დამატებითი სითბოს ნაკადის გათვალისწინება აუცილებელია და როცა მისი გათვალისწინება საჭირო არაა.