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SIMULTANEOUS HEAT AND MASS TRANSFER DURING CONVECTIVE DRYING

Erika SIMON[1] , Mária ÖRVÖS[2]

[1] UNIVERSITY OF SZEGED, COLLEGE FACULTY OF FOOD ENGINEERING
DEPARTMENT OF UNIT OPERATION AND ENVIRONMENTAL ENGINEERING
[2] BUDAPEST UNIVERSITY OF TECHNOLOGY AND ECONOMICS
FACULTY OF MECHANICAL ENGINEERING
DEPARTMENT OF PROCESS ENGINEERING

ABSTRACT

The decrease of the heat transfer coefficient can be observed during convection drying followed by simultaneous heat and mass transfer, when the continuity of the moisture-cover on the material-surface disappears. The purpose of our measurements was the demonstration of the reason of the fluctuating heat transfer coefficient. We examined the reacting force derived from friction in the case of wet and dry materials at different Re numbers. The volume of the heat transfer coefficient can be concluded from the received data of the reacting force.

1. INTRODUCTION

The fundamental theorem of the theory of similarity can be stated as follows: Two phenomena are similar if they are described by one and the same system of differential equations and have similar conditions of single-valuedness. For similar phenomena, it is necessary to have the same values of the similarity parameters. The criteria of similarity are necessary for the study of a given problem. Such an approach to the analysis of physical phenomena bears a somewhat formal character. The work of A. A. Gukhman stated that the theory of similarity has obtained a more detailed physical basis. On this basis the theory of similarity is acquiring a grater value as a theory of generalized variables.

Many variables and conditions of single-valuedness, enter into the differential equations for heat and mass transfer since the phenomena of heat and mass transfer are very complex. Not all these variables are essential for the development of the process of the heat and mass transfer.

For every problem there exists a whole complex of characteristic variables in which it must be considered. The transition to these variables permits of the reduction of a whole set of values essential for the process to a small number of independent variables and functions. The theory of similarity makes it its aim to work out general methods of determining such variables. It gives general methods for direct transformation of differential operators to very simple algebraic expressions.

The theory of A. A. Gukhman, The essence of the method of transformation is the replacement of the actual process by the simplest imaginarily scheme in which all the differential operators keep a constant value in space and in time in the given specific condition. In this case the expressions for the derivates are substituted by the quotient of the finite values. The Bi number and the Fo number can be derived by this method. Drying is a characteristically area of this method in the food industry. Simultaneous mass transfer- derivate from the evaporation of moist from the body- and heat transfer take place during convective drying and these two phenomena have a significant effect to one another. [1]

Many investigators (P. D. Lebedev and others) have established that in the evaporation of a liquid from a free surface or from porous bodies by convective heat supply, the coefficient of heat transfer is greater than that in the absence of evaporation – pure heat transfer – under identical temperature and hydrodynamic conditions.

Analytical calculations on the evaporating of a laminar boundary layer by blowing through with a light inert gas (mass transfer) show a special effect. As the velocity of the gas, which is blown through increases, the heat transfer coefficient increases.

Evaporation occurs at some depth below the body surface during the drying process. When the surface of the evaporation becomes deeper in a body, the heat transfer coefficient is higher than that with liquid evaporation from the body surface. The difference between the values of the heat transfer coefficients shows the Gu number: [1]

$$Gu \equiv \frac{T_a - T_b}{T_a} \qquad (1)$$

Where: T_a: absolute temperature of the airflow

T_b: adiabatic saturation temperature of air

Under conditions of forced convection, an additional new parameter Gu number (Gukhman number), which indicates the specific character of the heat and mass transfer in evaporating processes, must be introduced into the ordinary criteria expression of Nu=f(Pr, Re, Gu);

$$Nu = A \cdot \Pr^{0,33} \cdot \mathrm{Re}^{n} \cdot Gu^{m} \qquad (2)$$

Where: m,n are constants and the values of them depends on Re number.

2. EXPERIMENTS

The aim of our experimental work was the measuring and the proving of the difference behind the Gu- number. We postulated that the divergent flow circumstances coming from the different moistening of the surface cause the difference between the real and the theoretical heat transfer conditions. Figure 1 shows the convective drying equipment used at measuring.

We put the model material (12) hanging into the drying area. On that way, it could move only horizontally in the drying airflow.

During the drying, the air parameters – like the pressure, temperature, the air velocity- were measured and modified. (3, 4, 5, 13) At the same time, we measured the mass-change of the material (15) and the horizontal acting resistance-power at the material. The mass data were registered by the (14) balance, and the values of the resistance-power by the (15) balance. This data were forwarded to a computer. This computer registered the parameters of the drying air also. This experimental measure-system and method are suitable for registration of very small fluctuation of the resistance-power.

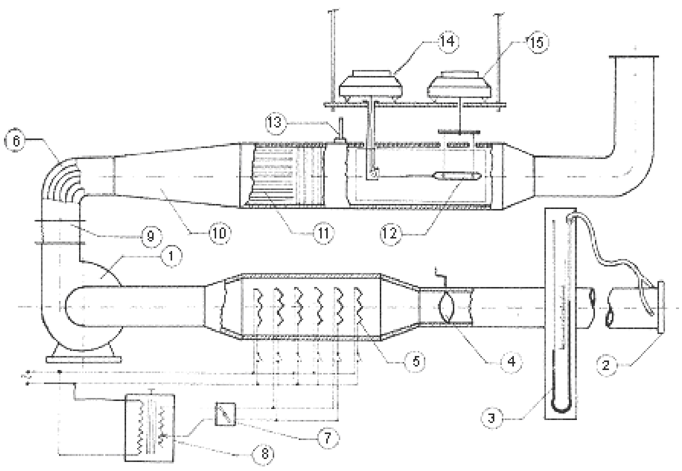

Figure 1.: The measure system
1. ventilator, 2. measure brim, 3. manometer, 4. close-fitting
5. filament, 6. air leader, 7. controller, 8. resistance
9. ventilator outlet, 10. increase channel, 11. leader lamella
12. model material, 13. thermometer, 14., 15. digital balance

3. RESULTS

The difference was studied between the measured and the theoretical heat transfer coefficient during the constant rate period of the convective drying.

The reason of the difference was supposed to fluid mechanical circumstances. [2] The surface of the body is totally covered with water during the constant period rate of the convective drying and mass transfer follows the heat transfer. An external velocity (u_0) and a slip-tension (τ_0) are supposed to appear on the moist surface.

Equilibrium equations described for the wet covered surface can justify that the evaporation of the moisture from the wet surface assists the mass transfer outbound of the body. This phenomenon resulted the improvement of the heat transfer coefficient. [4]

An opposite resistance to the blowing direction come out at a non friction-proof medium flow. This resistance factor is made up of a friction resistance and a form-drag. The friction resistance resulted from the friction tension come out on the dry surface. The wet covered bodies have better resistance studied under the same circumstances, than the bodies which surface is dry or slightly wet. The reason of the better resistance is the external velocity (u_0) and the slip-tension (τ_0)

We measured the resistance-power acted on the drying body put into the drying airflow. This measure process proved this phenomenon during the convective drying. This resistance-power is proportional to the value of the resistance factor. An inverse proportionality exists between heat transfer coefficient and the friction factor being in the formula of the resistance-power. [4]

5. CONCLUSIONS

On the basis of the received results, we can verify that the value of the resistance-power is grater on the dry surface of the body (E_{dry}), than on the moist surface (E_{wet}). The difference between the resistance-powers states the theory of the friction factor come out on wet surface.

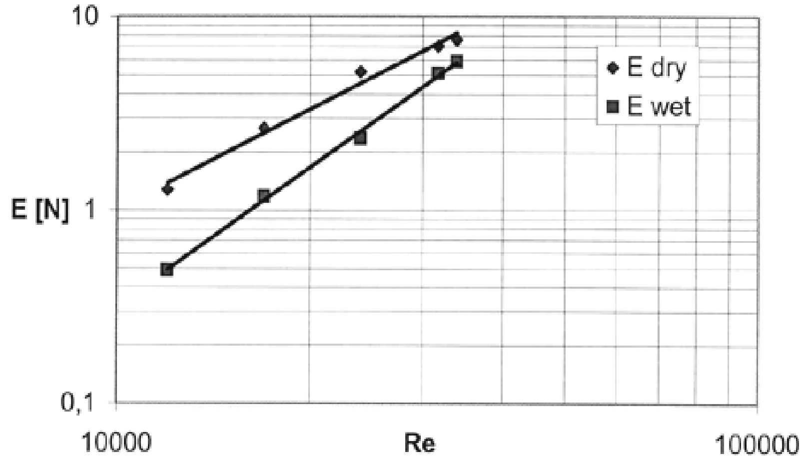

Figure 2.: Relationship between the resistance-power and the Re-number on wet and dry surfaces of the drying

The heat transfer coefficient is grater in case of water-covered body-surface than on dry surface. The reason of the better heat transfer condition can be the external velocity (u_0) comes out on the moist surface during the drying.

REFERENCES

[1.] Luikov A.V.: Heat and Mass Transfer in Capillary-Porous Bodies, Pergamon-press, Oxford, 1966.

[2.] Gruber J, Blahó M.: Folyadékok mechanikája, Tankönyvkiadó, Budapest, 1963.

[3.] SSU-Hsueh Sun, Thomas R. Marrero: Experimental study of simultaneous heat and moisture transfer around single shoprt porous cylinders during convection drying by a psychrometry method. International Heat and Mass Transfer. Vol. 39, No. 17. pp: 3559-3565. 1996.

[4.] Szentgyörgyi S.: Megmaradási elvek az ellenőrző felülettel határolt u_o felületi sebesség esetén. Kézirat; 2000.

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