INVESTIGATION OF HEAT TRANSFER PHENOMENON IN GREEN PEAS AT FLUID BED DRAYING AND TRAY DRYING

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ABSTRACT

In this paper, the heat transfer was studied in case of spherical material. Green peas were dried in a heat pump operated tray- and fluid bed dryer. The weight loss and the water content of the product were tested during each measuring set on different temperature levels. The physical properties of the samples were measured in the interest of determination of heat transfer data. The calculation of heat transfer on the basis of measured data was shown a difference from the results of heat transfer data – including dimensionless equations - derived from literature.

1. INTRODUCTION

Drying is a current method of dehydration and it has several types of realization. The water content of the product may influence the physical, the biochemical properties and the quality. This is why the dehydration technologies are very important area of the food industry and the agriculture.

Drying means the removal of the moisture content from a wet, solid material by turning a part of this moisture into gas state. The drying conditions influence the quality of the dried product. These conditions are the gas velocity, the inlet and outlet gas temperatures and the drying time. It is well-known that the energy consumption of the drying is very significant. The energy used for this unit operation represents that part of the process costs which reducible. Nowadays, the heat-pump dryers, especially heat pump combined fluidized bed dryers are being used for different types of products on industrial fields as well. Heat pump dryers reduced the energy consumption by 60-70% and improved the quality of the product. Since there is no exhaust to the surroundings heat pump driers are representing an environmentally friendly technology. [1,2] The aim of this work was the studying the heat transfer properties of a sphere-like, alive material using the fundament of the psychrometry method in a heat pump operated dryer.

2. MATERIALS AND METHODS

There are numerous methods available for measuring and calculating the heat and the mass transfer coefficients. These coefficients can be obtained by equations of dimensionless numbers like the Nusselt number and the Schmidt number. [3] The main purpose of this study was to determine more information about the heat transfer phenomena in case of higher air velocities and on four chosen temperature levels.

Apparatus and drying conditions

The apparatus consists of the drying chamber, the evaporator, the compressor, the condensers, the fan, the cyclone and valves. The system achieves a re-circulation of the drying air. The whole system is isolated therefore the drying conditions could be regulated with the temperature ranges from -10°C to 30°C. The temperature levels of the experiments were -5°C, +5°C, +15°C and +25°C. Each experiment was measured as a tray-dryer and as a fluid bed dryer on the atmospheric pressure. In order to avoid the oscillation of the drying air temperature the system was started 30 minutes before the drying. This duration was required for warm up or cooling down the air from the lab temperature to the selected drying temperature.

In the case of the 25°C temperature level, the experiment was repeated three times on different air velocities. The velocities are given in Table1.

Table 1. Average air velocities on the different temperature levels

Drying type	Air velocities [m/s]					
	-5°C	5°C	15°C	25°C-v_1	25°C-v_2	25°C-v_3
Tray	9,4	9,5	9,4	4,77	6,5	9,4
Fluid bed	7,1	7,6	7,9	7,5	8,2	-

The fluid bed drying took place in a chamber with the diameter of 0,24 m and a height of 0,6 m. For the tray drying, there was used a special basket made of 2 metal grinds with the diameter of 0,24m. The depth of the grinds was formed due to the average diameter of the green peas. The peas were placed between the two grinds which were clamped together during the drying.

The air temperature in the drying chamber was kept constant by a control panel and be measured with four sensors: two before the chamber and two after the chamber. The main air temperature was calculated as an average from these temperatures.

In case of fluid bed-like drying, there was taken samples from the main amount of material in order to check the average inside temperature and the wet content of the green peas. The inside temperature was determined with a tap-thermometer.

At the tray drying, the inside temperatures of the green peas were checked by two thermocouples. One of the thermocouples was taken into one seed placed in the free stream area and the other into a seed at the wall. The weight loss of the drying green peas were measured by a balance with an accuracy of ±0,1g in case of tray drying.

Samples

The material of the drying experiments was green peas which was kept frozen until the measuring. Each amount was taken for the experiments from the same quality because the green peas made from the same producer. The amount of the material was 700 gram at each fluid bed dryings. The average amount of the material was from 230 gram up to 250 gram in case of tray drying dependent on how the seeds covered the grind in one layer.

In case of fluid bed drying, the green peas were taken out from the freezing room a few minutes before drying in order to have the temperature near the drying air temperature. The melting time was shorter at the temperature level -5°C and a bit longer at 25°C level.

In case of tray drying, the period before drying was right enough to put the thermocouples into the green peas and fit together the grinds with screws.

Equations for calculating transfer coefficients

The equation (1) was verified with the *n*-exponent ranging between 0,4 and 0,66 for a sphere placed in different turbulent flows on the basis of mean heat and mass transfer experiments. [4]

$$\frac{\alpha}{k} = \rho c_p \left(\frac{Sc}{\mathrm{Pr}}\right)^n = \rho c_p (Lewis)^n \tag{1}$$

Lewis number associates the heat transfer with the mass transfer since it is quotient of the Schmidt number and the Prandtl number. The Schmidt number describes the mass transfer and the Prandtl number refers to the heat transfer. The eq. (1) can be inferred from the Chilton-Colburn's änalogy. Otherwise, the equation (1) can be written as follows:

$$\frac{\alpha}{k} = c_p \frac{M_{air} \cdot p_{atm}}{M_{water}} (Lewis)^n \tag{2}$$

The drying of a porous solid material with air of constant properties consists three main periods: 1-"settling down" period during which the body surface conditions reach the equilibrium with the air, 2-"steady-state" or "constant rate" period and 3- "falling rate" period. The falling rate period starts when the surface is no more fully wetted and the water vapour pressure starts to change. The psychrometry method is based on mass and the energy balance during the constant rate period. During the constant rate period, the energy supplied to the surface discharges the removed energy with the evaporation. The heat exchange by radiation is negligible in comparison with the exchanged heat by convection since the surface temperature is equal to the wet bulb temperature dependent on the air temperature and humidity at every point of the body.[5]

In case of convective drying, the heat transfer coefficient was assumed the same as the coefficient of the heat transfer only. This estimation could be inaccurate if the heat transfer is followed by moisture transfer. This coupled transfer phenomena may have a difference on the heat transfer coefficient in comparison with supposing only heat transfer.[6]

Traditionally, the heat transfer coefficients are estimated from dimensionless equations. In case of sphere like body the literature [7] suggests as follows:

$$Nu = 2 + (0{,}4 \cdot \mathrm{Re}^{0{,}5} + 0{,}06 \cdot \mathrm{Re}^{0{,}66}) \cdot \mathrm{Pr}^{0{,}4} \cdot \left(\frac{\eta_\infty}{\eta_s}\right)^{0{,}25} \tag{3}$$

$3{,}5 < \mathrm{Re} < 7{,}6 * 10^4$

$0{,}71 < \mathrm{Pr} < 380$

$1 < \eta_\infty / \eta_s < 3{,}2$

Nusselt number assumed as freely falling drops:

$$Nu = 2 + 0{,}6 \cdot \mathrm{Re}^{0{,}5} \cdot \mathrm{Pr}^{0{,}33} \tag{4}$$

$$3{,}5 < \mathrm{Re} < 7{,}6 * 10^4$$
$$0{,}71 < \mathrm{Pr} < 380$$

If the equations (3) and (4) are taken into consideration, the estimated heat transfer coefficient characterizes only the heat transfer without the simultaneous mass transfer. Several researchers took the coupling effects of moisture transfer on heat transfer into account in case of plate and cylinder (see eq. 5,6) bodies and suggested modified dimensionless equation [8] or introducing other factors [9,10] depending on the air temperature and humidity.

$$Nu = A \cdot \mathrm{Re}^{n} \cdot Gu^{m} \tag{5}$$

$$Gu = \frac{T_\infty - T_w}{T_\infty} \tag{6}$$

at cylinder: A=0,059; n=0,65; m= -0,44

Equation (7) is used to calculate the heat transfer coefficient by means of psychrometry method during the constant rate period.

$$\alpha = \frac{N_{const} \cdot r_{vap}}{T_\infty - T_w} \tag{7}$$

To calculate the Nusselt number by the calculated heat transfer coefficient:

$$Nu = \frac{\alpha \cdot D}{\lambda} \tag{8}$$

In this study, the prepared experiments and the calculations shows the different between the traditionally estimated heat transfer and the heat transfer with the coupled effects.

3. RESULTS

The settling down period was short at every experiment due to the high velocities and the small diameter (D=0,008m) of the green peas. The constant rate period of the dryings was estimated from experimental data. This constant rate period can be observed from the weight loss or the decreasing wet content of the material during the drying. In case of tray drying, Fig. 1 shows the weight loss at 25°C temperature level on different air velocities. Fig. 2 is shows the change of the wet content at the same temperature level in case of fluid like drying.

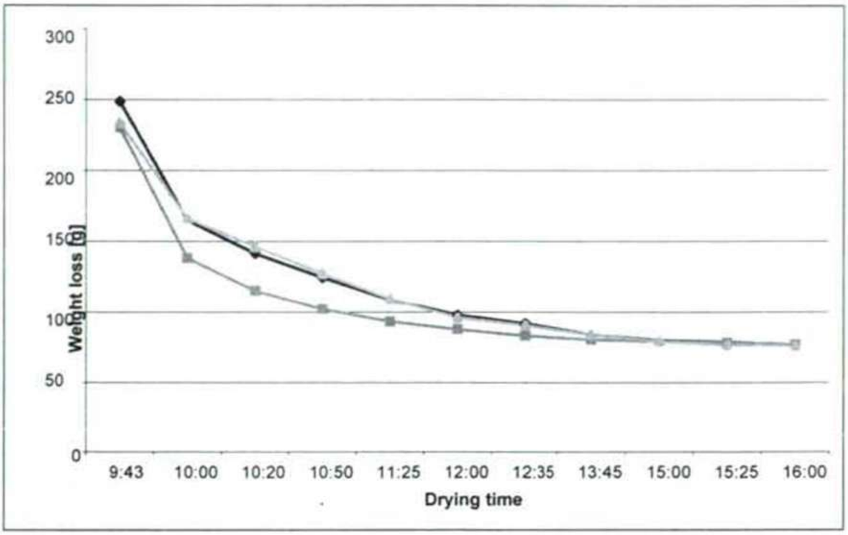

Figure 1.:Drying curves of tray drying at different air velocities at 25°C level

◊-lowest velocity; □-medium velocity; Δ-highest velocity

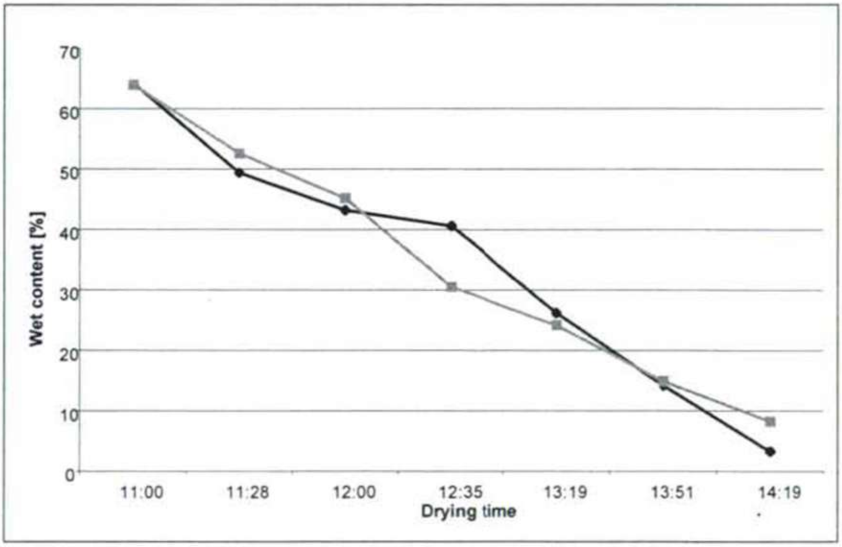

Figure 2.: Drying curves of fluid drying at different velocities at 25°C level

◊-lower velocity; □- higher velocity

The results obtained with the psychrometry method in the form of Nu=f(Re) and those derived with the equation (3) and (4) are compared in the Figure 3. and Figure 4.

	Nu_m	**Nu_l**	**Re**
25°C-v_1	60	28,3	2386
25°C -v_2	60,9	33	3260
25°C -v_3	64	40,5	4683
15°C	86	41,8	4979
5°C	98,4	43,4	5327
-5°C	91,3	44,7	5627

Figure 3.: Nusselt numbers (Nu_m) calculated from the measurements and Nusselt numbers (Nu_l) derived from dimensionless equation at tray drying

In case of tray drying, only the Nusselt numbers derived from the eq. (3) was applied since the particles were stuck by the basket. In case of fluid like drying, the particles were continuously floating during the drying operation therefore was a possible to use the equation of freely falling drops (Eq.4). Nu_{l1} means the Nusselt numbers calculated from eq. (3) and Nu_{l2} means the calculated value from Eq. (4).

	Nu_m	**Nu_{l1}**	**Nu_{l2}**	**Re**
25°C-v_1	71,76	37,77	36,3	4107
25°C -v_2	79,7	35,9	34,7	3741
15°C	77,75	38,2	36,6	4198
5°C	70	38,7	37,1	4310
-5°C	72	39,29	37,5	4380

Figure 4.: Nusselt numbers (Nu_m) calculated from the measurements and Nusselt numbers (Nu_{l1}; Nu_{l2}) derived from dimensionless equations at fluid-like drying

As shown from the Figures 3 and 4, the difference between the Nu_m and the Nu_l; Nu_{l1} and Nu_{l2} are in average two times higher. This difference is presented well on the Figure 5. at the temperature level 25°C at three different air velocities.

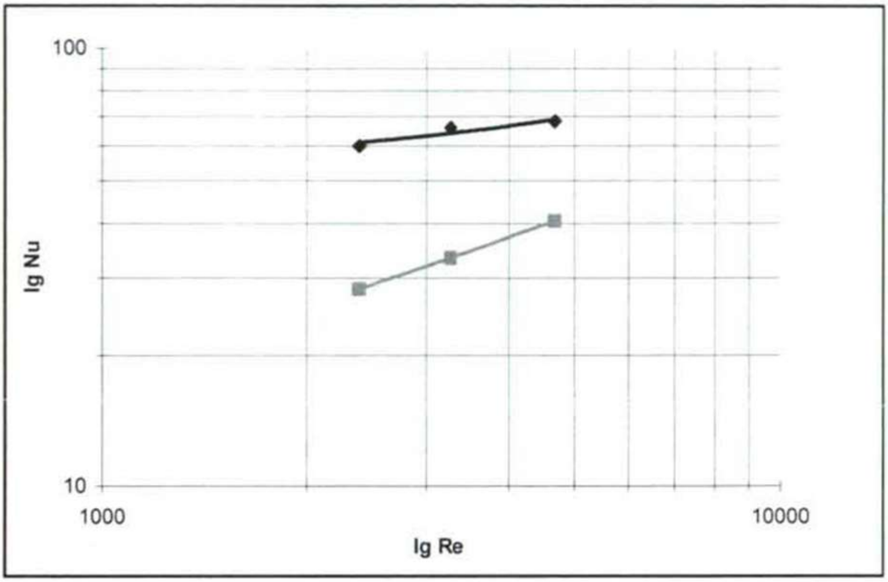

Figure 5.: Correlation of calculated and derived Nusselt numbers as a function of Reynolds number at 25°C level in case of tray drying

◊-Nusselt number calculated from measured data (Nu_m);
□- Nusselt numbers derived from dimensionless equation taken from literature

The experimental results of this study show the discrepancies at every measurements made with sphere body at different temperature levels. This divergence were obtained and studied at plate and cylinder bodies in many cases by other researchers. Their predicted works and articles gave a mathematical solution for the calculation of this coupling phenomenon. At spherical body, there are less studies about the coupled heat and mass transfer. [4, 11]

4. CONCLUSIONS

The psychrometry method used for this experimental study worked well to determine the convective heat transfer coefficient around sphere like dried material. The Nusselt number calculated from measured data is near twice larger than the predicted Nusselt number for heat transfer only at the same range of Reynolds number. This work could be the essential fundament of furtherer calculations which are necessary to estimate a Gu-like number or find a more suitable equation and mathematical model for the simultaneous heat and mass transfer in case of sphere bodies.

Although, this experimental observation supported the previous theories in connection of drying sphere like bodies, further experiments and calculations are necessary. It is also necessary to take into consideration other circumstances like the shrinkage of the material on the higher temperature levels, the turbulent air stream at higher velocities as factors of influence. To calculate the mass transfer on the same way and by the same circumstances indicate further studies as well.

Nomenclature

c_p	Specific heat [J kg^{-1} K^{-1}]
D	diameter of the sphere [m]
D_t	thermal diffusivity [m^2 s^{-1}]
M	'molecular' weight [kg]
N	mass flux [kg m^{-2} s^{-1}]
r_{vap}	Latent heat of evaporation [J kg^{-1}]
T	temperature [K or °C]
p_{atm}	atmospheric pressure [Pa]
k	mass transfer coefficient []
X	wet content [%]
v	velocity [m s^{-1}]

Greek symbols

α	Heat transfer coefficient [W m^{-2} K^{-1}]
η	Viscosity [kg m^{-1} s^{-1}]
ν	Kinematic viscosity [m^2 s^{-1}]
λ	Thermal conductivity [W m^{-1} K^{-1}]
ρ	Density [kg m^{-3}]

Dimensionless groups

$Re=D^*v/\nu$	Reynolds number
$Nu=\alpha D/\lambda$	Nusselt number
$Pr=\nu/D_t$	Prandtl number
$Sc=\nu/D_{ab}$	Schmidt number
$Gu=(T_\infty-T_w)/T_\infty$	Gukhman number
Lewis=Sc/Pr	Lewis number

Subscript

s	surface condition
w	wall condition
∞	free stream condition

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