DETERMINING THE MOISTURE CONTENT AND THE TEMPERATURE OF AIR AND OF A MATERIAL AT THE EXIT FROM A WET FLUIDIZATION BED

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A mathematical model has been developed which describes the processes of heat and mass transfer in a wet fluidization bed during assimilation of the liquid by the solid particles while heat of reaction is released (or absorbed). A correlation between this model and actual processes is established.

In engineering one often deals with processes where liquid evaporates from the surface of a wet granular material in a fluidization bed. The purpose of such processes is either to dissipate the heat of chemical reaction and to provide cooling, also to hydrate the granular material [1, 2], or to saturate the liquid with vapor and to lower the temperature of the gas which passes through the apparatus.

In the technical literature there is hardly any information available on the design of such processes. The only reference known to the authors is the article by J. Cyborowski and A. Selecki [3] where limiting values of volume mass transfer coefficients and their dependence on the mass flow rate of fluidizing air are reported.

In this study we will present an analytical solution from which exact values of both the air and the charge parameters at the exit from a fluidization bed can be calculated.

Fig. 1. Schematic diagram for calculating the process of moisture evaporation from a wet fluidization bed.

Fig. 2. Comparison between measured and calculated values of air humidity (1) and air temperature (2) at the exit from the fluidization apparatus.
The process is represented schematically with all essential symbols in Fig. 1. We consider the
one-dimensional problem along the x-axis in the direction of the air flow. The following assumptions are
made here:

1. Solid particles in the fluidization bed mix perfectly and, consequently, are all at the same tem-
peratures.

2. In formulating the differential equations it is assumed that both the evaporation process and the
heat transfer obey the conventional laws of heat and mass transfer.

3. The process is steady.

The differential equations describing the processes of heat and mass transfer can be written as fol-
lows:

\[ \frac{d\theta}{dx} = \beta P \frac{d}{dx} \left[ \frac{\partial}{\partial x} \left[ \frac{\alpha F}{T} \right] \right], \quad (1) \]

\[ \frac{d\theta}{dx} = \frac{\beta F c_p c_s}{g_A} \left[ \frac{\alpha F}{T} \right] \left[ \frac{\partial}{\partial x} \left[ \frac{\alpha F}{T} \right] \right] + \frac{\beta F c_p c_s}{g_A} \left[ \frac{\alpha F}{T} \right] \left[ \frac{\partial}{\partial x} \left[ \frac{\alpha F}{T} \right] \right] \bigg[ \frac{\alpha F}{T} \right]. \quad (2) \]

From the material balance and the heat balance follows

\[ \left[ \theta_0 - \theta_t \right] c_v + c_D \left[ \theta_0 - \theta_t \right] - \left( \theta_t - \theta_0 \right) + T_c w \left( \theta_t - \theta_0 \right) + \rho \frac{\partial}{\partial x} \left[ \theta_t \right] + \left( \rho c_w + \rho \theta_t \right) + Q = 0. \quad (3) \]

Integrating Eqs. (1) and (2), we find

\[ \frac{\beta F P_0}{g_A} H \left[ 1 - \frac{\alpha F}{T} \right] = z_0 - z_0 - \frac{K}{1 - \frac{\alpha F}{T}} \ln \left[ \frac{z(T) - \frac{\alpha F}{T}}{z_0 - \frac{\alpha F}{T}} \right], \quad (4) \]

and

\[ \frac{\theta_t - T}{\theta_0 - T} = \left[ \frac{\frac{\alpha F}{T} \left( z_0 + c_v \frac{\alpha F}{T} \right) \left[ 1 + A \left( \frac{\alpha F}{T} \right) + A^2 \right]}{\frac{\alpha F}{T} \left( z_0 + c_v \frac{\alpha F}{T} \right) \left[ 1 + A \left( \frac{\alpha F}{T} \right) + A^2 \right]} \right] \left[ \frac{z(T) - \frac{\alpha F}{T}}{z_0 - \frac{\alpha F}{T}} \right] \left[ \frac{\alpha F}{T} \right] \left[ \frac{\alpha F}{T} \right] \frac{K c_v}{P_0 \left[ 1 - \frac{\alpha F}{T} \right] \left[ 1 + A \left( \frac{\alpha F}{T} \right) + A^2 \right]} \right. \left. \right]. \quad (5) \]

The system of Eqs. (3), (4), (5) relates the process output parameters with the input quantities, which
makes it feasible to derive several important practical formulas.

The validity of this mathematical model was verified by comparing the output parameters according
to the proposed model with respective test data. The calculations were made on a computer.

We used the test data by J. Cyborowski and A. Selecti [3] pertaining to the case of maximum mois-
ture content in a fluidization bed and our test data for a glass model 30 mm in diameter and 300 mm high.
As the solid material we used electrical-grade corundum grains 0.25, 0.80, and 1.5 mm in diameter. The
air velocity per total apparatus section was varied from 0.83 to 3.99 m/sec, the air temperature at the
exit was varied from 11 to 18°C and its humidity from 6 to 12 g/kg. The height of the dense bed was varied
from 25 to 100 mm. Water was supplied to the apparatus in an amount sufficient to compensate for evapo-
rated moisture and to cover all particles with a water film.

The quantities needed for these calculations were determined as follows.

The surface of particles F per unit bed height and per unit gas distributor area was calculated ac-
tording to the expression

\[ F = \frac{6 (1 - \varepsilon)}{d_c}. \quad (6) \]

The bed porosity \( \varepsilon \) was calculated according to the O. M. Todes formula [4].

Inasmuch as the surfaces of particles in the fluidization bed were covered with a water film, the
values of the mass transfer coefficient were taken from the data in [5] (L. D. Berman). The heat transfer
coefficient \( \alpha \) was determined from the known ratio \( \alpha / \beta = 0.33 \sim 0.35 \) kcal · atm/kg · °C valid for evaporation
from the surface of a water film.

For our tests we estimated the amount of heat leaking in from the ambient medium. It was ascer-
tained that this heat could not contribute more than 0.06°C to the temperature rise at the apparatus exit
— well within the accuracy limits of the measurements. For this reason, the effect of heat leakage was
henceforth disregarded.