USE OF BIOT NUMBER ANALYSIS FOR GRAIN DRYING

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Abstract: Different approaches of calculation procedures during corn drying including different Biot numbers are presented in the paper. It is common to use an assumption of uniform temperature in the papers dealing with drying, especially thin layer drying. Conventional analysis does not reflect the evaporative effect. In this paper temperature uniformity is analyzed during the whole process of thin layer corn drying. Dependency of free moisture content during time is also presented.

Key Words: Biot number / Corn Drying / Heat Transfer / Mass Transfer

1. INTRODUCTION

Drying process is one of the most complex unit operations because it involves simultaneous coupled heat and mass transfer phenomena. In order to make the process less complicated for the mathematical description, some assumptions need to be done. During the analysis of drying process it is a common approach to make an assumption of uniform temperature, especially when dealing with thin-layer drying. In order to get insight in the process involving evaporative effect, one should do a more complete Biot number analysis [1]. Using a Biot numbers analysis is possible to identify controlling mechanisms knowing the relation between internal and external resistances to mass or heat fluxes. In [2] a method of classification and division between an isothermal and uniform temperature profile model is proposed. This classification is made according to value of Le (Lewis number) and product of these two numbers LeBi number. According to this classification, the isothermal model of sorption would be valid if LeBi>100 and the uniform temperature profile model of sorption is valid for Le>10. Calculation of Lewis number is therefore used for determination whether heat transfer is the limiting process or not. The assumption of isothermal model supposes a constant and uniform temperature of the solid, where only one parameter, the diffusivity, is necessary for describing the drying kinetics.

In contrast to isothermal model, the uniform temperature model needs two parameters for description of drying kinetics, diffusivity and the heat transfer coefficient.

2. ANALYSIS AND RESULTS

The basic (heat) Biot number (or better “Biot criteria”, as it is called in [3]) is defined as

$$Bi = \frac{h \cdot L}{k}$$

(1)

For spherical object, e.g. the characteristic length $L$ is the radius of the sphere. For slab, e.g. it is the width of the slab.

There are several other definitions, including the surface/inner evaporation. In case surface evaporation is predominant, the definition of Biot number is taking the following form:

$$Bi = Bi^* + \frac{\Delta H_L \cdot \dot{S}_i}{(T_x - T_{s,2}) k}$$

(2)

In case of internal evaporation the equivalent Biot number, $Bi^*$, can be defined as follows:

$$Bi^* = \frac{h \cdot L}{k} \cdot \frac{T_x - T_0}{T_x - T_i}$$

(3)

while Biot number is defined by following expression:

$$Bi = \frac{h \cdot L}{k} = \int_{x=0}^{x=L} F(x) \cdot dx \cdot Bi^*$$

(4)

While the assumption of the uniform drying rate across the thickness, $L$, is valid, the former could be written as:

$$Bi = 2 \cdot Bi^*$$

(5)

At Figs. 1-4 several different results depending on drying air temperature are presented. The simulations are made in COMSOL (2 dimensional analysis) for the cases of air drying temperatures above the box sample 0.2x0.2x0.2m with isolated bottom and side walls kept at constant temperature of 15°C. Above the sample, convection of drying air at temperatures 50, 75, 100 & 120°C consequently is employed. Following values
(according to data for corn given in [4]) are used in the simulations:
\[ h = 56.7 \text{W/m}^2\text{K} \]
\[ k = 0.15 - 0.24 \text{W/(mK)} \]

It is assumed that the layer of the dried corn grains can be considered as a homogeneous body with dimensions (in 2 dimensional coordinates 0.2x0.2m).

At Figs. 5-6 are shown streamlines of heat fluxes for the analyzed cases. The changes of heat fluxes streamlines are noticeable with the increase of air drying temperatures.

\[
Bi = \frac{T_{S1} - T_{S2}}{T_{S2} - T_{\infty}} = \frac{hL}{k} = \frac{L}{1/h} = \frac{R_{int}}{R_{ext}}
\]

where \( T_{S1} \) and \( T_{S2} \) are the side temperatures of the slab and \( T_{\infty} \) is the temperature of the surrounding fluid (in this case drying air).
In case of negligible external resistance, the value of Bi number is approaching infinity, which is the case in these simulations, too.

If we can assume the wide spread assumption used for drying of thin materials that $Bi<0.1$, then we will be allowed to assume that we have uniform temperature distribution spatially uniform [5]. It is not the case in the analyzed examples, because we have (according to equation (1) $Bi=56.7$).

3. CONCLUSIONS

In the analyzed cases, under the conditions used in this paper and for the given sample, the assumption of uniform temperature distribution does not stand. It could point to the fact that maybe the sample is not thin enough.

In the analyzed cases, as it is also confirmed in [6], there is a negligible external resistance.

4. NOMENCLATURE

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
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<tbody>
<tr>
<td>$Bi$</td>
<td>Biot number</td>
</tr>
<tr>
<td>$\Delta H_L$</td>
<td>latent heat of water vaporization</td>
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<tr>
<td>$h$</td>
<td>heat transfer coefficient</td>
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<tr>
<td>$k$</td>
<td>thermal conductivity</td>
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<tr>
<td>$L$</td>
<td>characteristic length</td>
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<tr>
<td>$Le$</td>
<td>Lewis number</td>
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<tr>
<td>$R$</td>
<td>resistance</td>
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<tr>
<td>$T$</td>
<td>temperature</td>
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<tr>
<td>$x$</td>
<td>linear coordinate</td>
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Subscripts

- $\infty$ bulk fluid
- $1, 2$ surface side
- $0$ center

Superscripts

- * equivalent

5. REFERENCES


