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Reducing the Energy Consumption of Seed-corncob Drying by Means of a Thermal Analysis Method

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Abstract: One of the main tasks of seed dryer technology is to optimize the cross effects between the energetic and quality aspects. Carrying out an industrial-scale experiment it was found, that the change of the moisture distribution in corn-cob and in corn-kernels differs during the drying time. However, both depend on the sort of seed and on the established drying technology. Moisture loss of corn-kernels is quite uniform along the layer depth, and it changes uniformly during the drying time while corn-cobs show different features from this point of view. The inlet and outlet drying air velocity and drying air temperature maps manly influence the dominant factors of the drying process. Furthermore, some local technological parameters (e.g. local density of drying material, distance between the fan and the drying chamber, local shrinkage behaviour, etc.) significantly modify the impact of drying air on the dehydration process. An appropriate method was developed to describe and to predict the characteristic energy and mass transfer processes that take place inside the corncobs and in the bulk. On the basis of the experiment results a modified drying routine was worked out. By applying the modified technology it resulted significantly less energy consumption while the original quality criteria were kept.
Key words: seed-corncob drying, industrial dryer, hot air drying, convective drying

INTRODUCTION and LITERATURE REVIEW

Development of seed drying process in a hybrid plant is one of the most crucial element of the corn production technology. As it is widely known in the seed drying technology the long residence time increases the energy consumption (and the costs) most significantly. In order to reduce the energy costs while the product quality criteria are kept we must calculate the expecting drying time as exactly as possible. For this aim a process simulation which is based on an industrial scale experiment seems an appropriate tool.

Drying seeds together with corn-cobs usually can be considered as deep bed dehydration process of non-homogeneous materials. Some deep-bed drying models, which are based on heat- and mass balance equations (1) assume the existence of an equilibrium state between the dried material and the drying medium. Hence, they utilize the equilibrium moisture equation of the material to solve the problem. However, equilibrium exists only by slow drying at a low medium temperature and a low air-change ratio. The other type of simulation, the co-called MOREY'S BTM model (2) takes the rehydration effect into consideration, which occurs at the beginning of the drying process. Using the validity area of slow drying, low medium temperature, and low air-change ratio, this method, however, is not much different from the classical theoretical models: it is complicated and hardly usable in the practice (3-5).

The well known Hukill-method seems more practicable for decribing the deep bed drying. Hukill (6) assumed, that in the case of convective drying the heat demand of the dewatering process equals the change of enthalpy of the drying medium. He used a semi-empirical model with which it was easy to calculate, but his model ignored the effect of the changes in the inlet drying medium properties as well as the role the moisture change in the drying medium played during the drying process.

$$MR = \frac{2^{\Delta}}{2^{\Delta} + 2^{\Gamma} - 1} \qquad (1)$$

However, Equation (1) does not take the potentional local rewetting into consideration and this inadequency causes an non-ignorable mistake in predicting the drying time. According to the existing equation [$MR=(X-X_e)/(X_0-X_e)$], kinetic curves can be determined. In order to make the classical Hukill-model more precise the dimensionless pressure (Π) must be introduced that helps us to count with the potential local or initial rewetting (7) as follows:

$$\Pi = 1 - \frac{p_{s_{in}} - p_{out}}{p_{s_{in}} - p_{in}} \quad (2)$$

The original Hukill-equation (1) will be valid if Π converges to zero, so (p_{in}-p_{out})$\rightarrow$0, as well. As for generalizing the Hukill-equation, the instantaneous value of the moisture ratio must be determined in order to simulate the re-watering at the beginning of the drying process:

$$MR = \frac{2^{\Delta} + 2^{\Pi} - 1}{2^{\Delta} + 2^{\Gamma} - 1} \quad (3)$$

By applying Equation (3) a more precise model can be derived and the topical moisture ratios in the bulk and the needed drying time can be predicted more accurately (7,8) in spite of that it is rather easy formula.

THE MEASURING SYSTEM

A novel industrial corn-cob dryer was measured in our research where some drying chambers with high importance were analyzed in detail. The dryer itself is specialized for seed corn production hence precise drying is crucial for the sake of the appropriate material quality.

The drying chambers of numerous corn-cob dryers have trapezoid shapes (Figure 1., A-A section) with aeration grids (windows) at its bottom and top as well as sideward.

The top view of schema in Figure 1. shows the offset arrangement of the sampling mines. It was installed just only 3 pieces of sampling mines within a drying chamber not to make the drying circumstances disturb significantly.

Aeration settings can be seen at the bottom right corner of Figure 1. There were two basic solutions to aerate the drying chamber: The drying air with medium temperature level comes from the bottom grid up to the top of the batch (Figure 1., setup A.; black grid: closed; white grid: opened), which carry away the main moisture mass from the drying material. After a given period of time the settings are reversed between setups A and B, hence the drying air with high temperature level comes from sideward grid down to the bottom of the batch (Figure 1., setup B. ; black grid: closed; white grid: opened) make the drying material achieve the aimed moisture content.

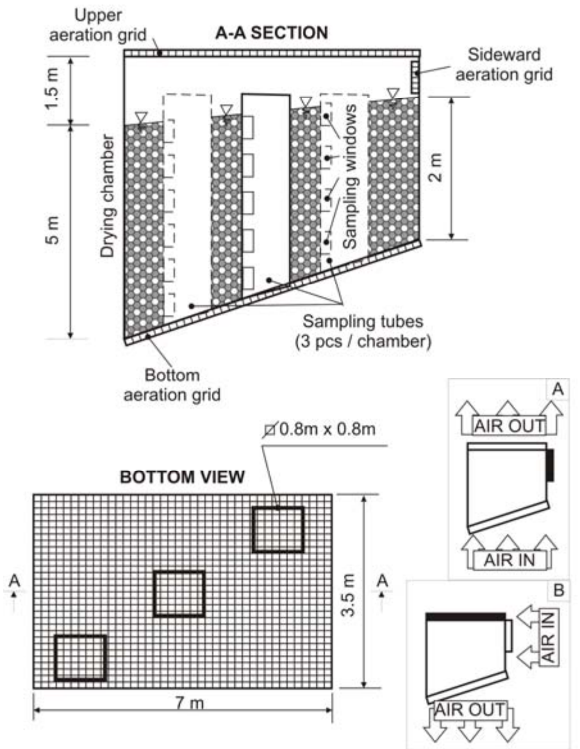

Figure 1. Structure of the drying chamber (A: 1st setup of aeration; B: 2nd setup of aeration)

Covering of each grids consist several solid air-proof window, that is why volume flow of drying air can be adjusted be the opening or closing of some or several closing-window above the grid. Function of these windows was automatic, moreover the state of each window was registered during the measurement.

An expediently developed data acquisition equipment (Eltek RX250AL with GENII radio data logging system, Darca Plus software) was applied to collect the information of the sensors (Figure 2.). Being the circumstances of the measurement very special, radio wave sensors were used and installed into the deep of the sampling mines.

There were used two types of sensors: one of them measured the temperature only, the second one measured the temperature and the relative humidity, as well. The properties of the drying air were measured by the second sensor type, and that of the drying material by the first sensor type.

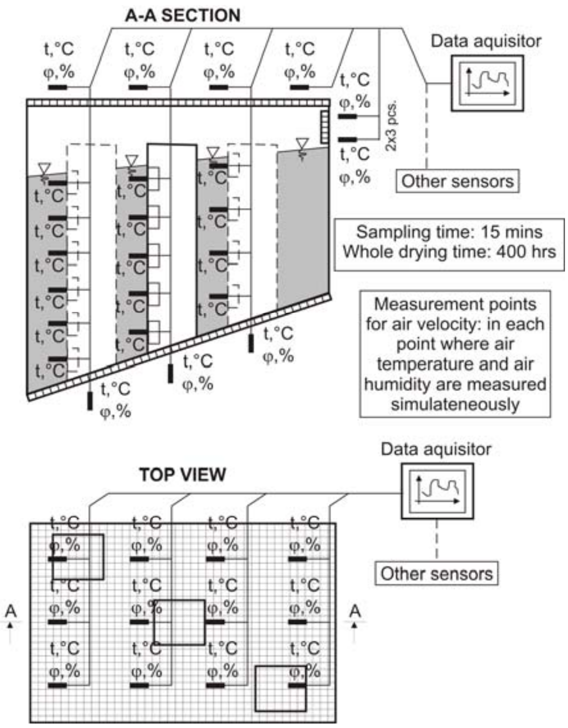

Figure 2. Assembly of the main data acquisition system for measuring the temperature and humidity of drying air and the temperature of drying material

An average drying period was about 72 hours, consequently sampling time of 15 minutes was adequately precise for this measurement.

The velocity of drying air was measured at each opened aeration window; the measurement points were the same like that of the coupled air temperature and humidity measurement points. Other velocity measurement points coincide with the installation place of the coupled sensors.

RESULTS and DISCUSSIONS

Figure 3 shows the change of the moisture content of the corn-cob along the drying time and the layer depth. It can be determined, that, the bottom layer of the batch began to dry more rapidly that the top indeed at start the initial moisture content varied slightly along the depth of the batch. Firstly aeration setup A. (Figure 1.) was used, then after about 30 hours of drying aeration setup B. (Figure 2.) was chosen and applied. After reversion the moisture content of the bottom layer of the drying batch stayed at a constant level, but the moisture content of the upper layer began to decrease rapidly.

The moisture distribution in the corn kernels (Figure 4.) differs significantly from that of the corn-cob (Figure 3.). Firstly the initial moisture content, and secondly the shape of the diagram is conspicuous. The initial moisture content of the corn-cob is much higher then that of the corn-kernels, so it is obviously, that in case of the corn-cob and corn-kernels system the main water reservoir unit is the corn-cob, which results a definite water movement from the cob to the kernels. According to the Figure 4. it can be determined, that the moisture content of the corn-kernel decreases rapidly and more uniform along the layer depth.

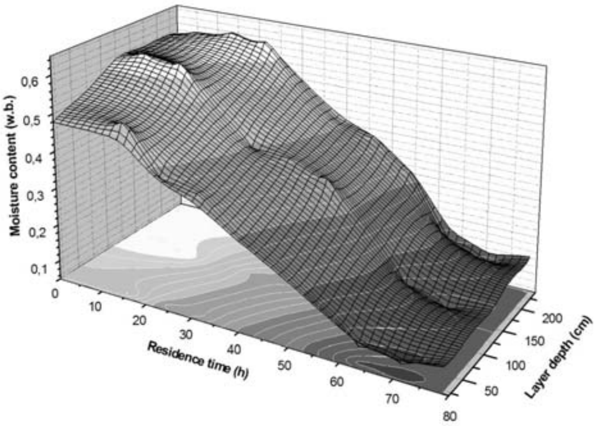

Figure 3. Typical integrated moisture content of the corn-cob as functions of the drying time and layer depth

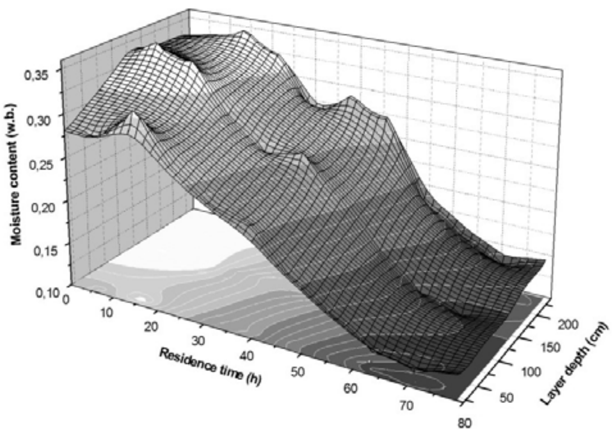

Figure 4. Typical integrated moisture content of corn-kernels as functions of the drying time and the layer depth

The typical temperature field of corn-cob can be seen in Figure 5. As the picture shows the batch between the 160 cm and 220 cm warms up more slowly then the other part of that. The hottest part is the bottom layer until, in this way the temperature difference within the batch could hit the 5°C.

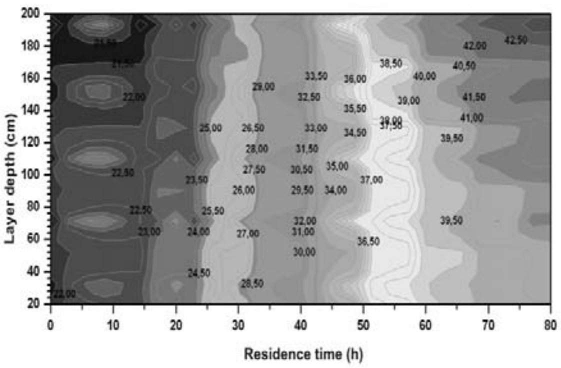

Figure 5. Characteristic temperature map of the corn-cob as functions of the layer depth and the drying time

The temperature field of the bulk shows more uniform distribution (Figure 6.), but the bottom part of the batch seems to be up to 5°C colder then the other part of that.

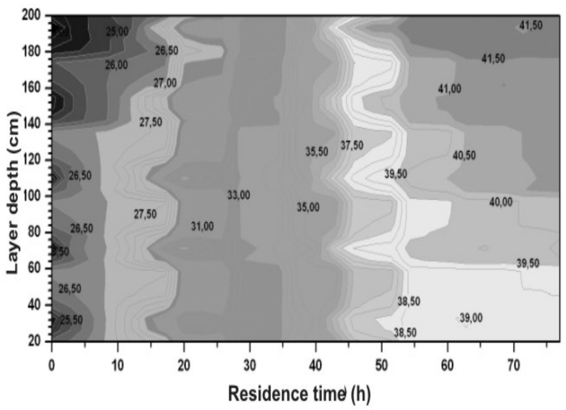

Figure 6. Temperature of the bulk as functions of the layer depth and the drying time

On the basis of the accumulated data the modified Hukill-curves can be drawn that obviously show the rewetting process at the beginning of drying (Figure 7.). After that the Figure 4. can be interpreted much easier, taking into consideration that the drying air direction – as the part of the applied technology – was changed 40 hours after the drying process started.

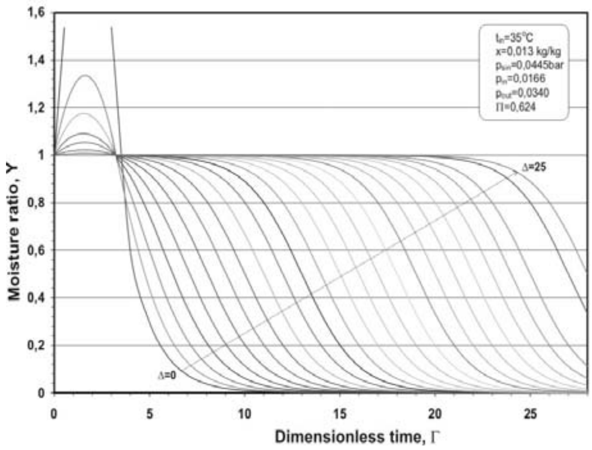

Figure 7. Modified Hukill-curves based on the seed-corncob drying conditions without changing the drying air direction

By taking in account all the measuring data and observation the Figure 8 can be derived that evidently demonstrates the overdrying and it points out its reason: the delayed change of air direction. After a thermal analysis like discussed above the drying technology can be appropriately determined, taking the material features, the drying construction and other local conditions into consideration.

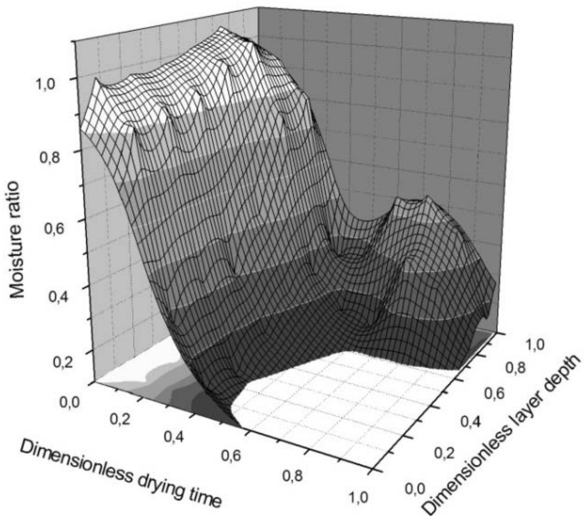

Figure 8. The local overdrying as the influence of the delayed change of drying air direction

CONCLUSIONS

It was found, that the change of moisture content of the corn-cob and that of the corn-kernels differ during the drying process. Moisture loss of corn-kernels are quite uniform along the layer depth, and it changes uniformly during drying. The corn-cob shows different behavior, because it dryes irregularly, depending on numerous local considerations as well.

Layers situated closer to the cross section of the entering drying air dry more rapidly that can cause local overdrying. By changing the drying air direction in time the overdrying and by increasing the drying air ad interim the local rewetting can be avoided. The appropriate time for changing the air direction is the moment when the moisture content of ear components are equal to each other. The increase of airflow at the beginning of the drying process and just after the changing of air direction helps to prevent the rewetting phenomena.

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NOMENCLATURE

Δ: Number of uniform layers
Γ: dimensionless time
k: drying coefficient
p: partial vapor pressure [Pa]
Π: dimensionless pressure
τ: time [h]
t: temperature [^{o}C]
X: material moisture content [kg/kg, d.b.]
x, y, z length [m]

Indexes

0: initial value
a: drying air
e: equilibrium
in: inlet
out: outlet
s: saturated
v: vapor
w: water

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