TEMPERATURE MODES OF GRAIN DRYING IN CONVECTIVE DRYER AND FEATURES OF A THERMAL CAPACITY OF GRAINS

R. Aliev
B. R. Bekkulov
M. T. Xalilov

Follow this and additional works at: https://uzjournals.edu.uz/adu
TEMPERATURE MODES OF GRAIN DRYING IN CONVECTIVE DRYER AND FEATURES OF A THERMAL CAPACITY OF GRAINS

R. Aliev, B. R. Bekkulov, M. T. Xalilov

The article presents a nomogram for determining the value of the heater power providing the operating temperature in the dryer drum of the device, the method of experimentally determining the specific heat capacity of the grain mass and the results of the experiments are compared with the given literary values. The definition of drying time is shown using the obtained nomogram and using the specific heat capacity value to calculate the required amount of heat.

Keywords: grain, paddy, rice, heat capacity, heat quantity, thermo-physical properties, volume of the drying drum, power of a hot-air heater, drying device.

1. Introduction

For the long-term storage and processing of cereal products, a pre-drying process is required. Otherwise, favourable conditions will be created for the propagation of pathogenic microorganisms and the share of the losing crop will increase. A sufficiently dried grain prevents the multiplication of bacteria and thus ensures a long-term storage of it in granaries. The drying process includes multi-stage physical processes, which are interrelated with each other in a certain order. The first stage of the drying process is the evaporation of moisture from the surface of the grain due to the heat supplied to it by the drying agent. Then, the moisture is removed from the inside of the grain to the surface, which is subjected to evaporation. The last step is the removal of moisture from the dryer chamber and the release of evaporated moisture into the atmosphere [1].

The temperature of the drying agent is the most important parameter of the drying process, which has a significant effect on the quality parameters of the grain. It is known that the process of evaporation of moisture occurs at relatively high temperatures. However, drying at high temperatures leads to the following undesirable phenomena: seed usability is lost for the next crop, the quantity and quality of vitamins decreases, and grain cracks appear [2.p.36]. To ensure the seed suitability of the grain for the next sowing it is recommended to keep the drying temperature no more than 43°C [3.p.27]. In particular, the paddy drying differs sharply from the drying of other types of cereal products. Our studies have established that the optimum temperature for effective drying of the shala mass is up to 35°C [4.p.43]. When the drying temperature rises, an undesirable phenomenon is observed—the appearance of cracks on the grain of rice, which contributes to the increase in the amount of the rice cut during further mechanical processing. Consequently, the quality of the purified rice is reduced. To improve the quality of grain drying, it is necessary to study the heat exchange. To study heat transfer processes in drying plants and natural conditions, it is necessary to know the thermo-physical properties of grain crops.

The literature gives the specific heat values of wheat grain, in particular rice. The heat capacity of wheat grains is determined between the heat capacity of the dry matter and the heat capacity of water, and the heat
capacity of the dry matter is 0.37 kcal / (kg · °C) [5.p.57]. Specific heat of rice and chaff is 0.782 kJ / (kg · °C) and 1.2 kJ / (kg · °C), respectively [6.p.110]. The study [7.p.105] is devoted to the determination of the specific heat of some major crops at different moisture contents and temperatures using the mixing method. The results showed that the specific heat capacity of the grain increases with increasing moisture content, decreases with respect to temperature. Study [8.p.355] «development It was essential to use a standard material of accurately known specific heat for development work and aluminum (specific heat 0.21) was selected for this purpose. As cooled liquids were involved. it was decided, initially, to use the method of using a vacuum flask as a calorimeter; tared amounts of aluminum at known temperatures were added to tared amounts of toluene, at about 1 °C, contained in a vacuum flask. Temperature readings were taken every minute or so before and after adding the aluminum and the true temperature rise was obtained graphically. Despite completely standardizing the procedure and the use of various thermal shields, repeatable results could not be obtained and the vacuum flask technique was rejected». In [9.p.1], the measurement of the specific heat capacity of brown rice and raw rice of Basmati variety was carried out using a version 3.6 calorimeter. (Phonics, Germany). In [10.p.1], the specific heat capacity was determined using DSC, thermal conductivity by the probe method and volumetric thermal conductivity, indirectly dependent on bulk density, specific heat capacity and bulk thermal conductivity. In work [11.p.338] «the specific heat of hard red spring wheat is a linear function of both temperature in the range −33·5 to 21·8°C and of moisture content in the range 1 to 19% wet weight basis. The specific heat of wheat containing 23·4 and 29·6% moisture is not a linear function of temperature and moisture content. Latent heat of fusion is released by wheat containing 23·4 and 29·6% moisture in wide ranges of temperature below 0°C. Moisture in wheat containing 19% or less moisture does not appear to undergo a change in phase down to −33·5°C. Above 0°C the heat content of moisture in wheat appears to be greater than free water. Specific heat of wheat is not significantly affected by dockage in the wheat or by the year of harvest». The study [12.p. 81] presents the results of tests that determine the specific capacity and thermal diffusivity of rape. For the experimental study of the thermo-physical properties of granular, hard materials, a literature review [13,14,15,16,17,18,19] was made.

The purpose of this work is to create nomograms that take into account the interrelationships of the main physical parameters in order to ensure the required optimum air temperature for an effective drying process, determine the amount of heater power and an experimental study of the specific heat at normal atmospheric pressure, room temperature and known humidity of various materials in the form of granules and granulated products in backfill.

The final task is to determine the required amount of heat to ensure optimal air temperature, the duration of heating before the start of the drying process in the dryer drum of the device and the method of experimental determination of the heat capacity of grain products in the mound.

2. Metod
2.1. Theoretical studies
In the device designed by us, a convective drying method is applied [20]. According to the recommendations given in [3.p.27], the supply of warm air along the flow of grain is provided. The drying drum has the shape of a cylinder and rotates. To create warm air in the drying drum an electric air heater is used.

Determination of the amount of time required to achieve the required air temperature inside the dryer drum of the device for drying grain products. Conditionally accept that there is no heat exchange with the environment, since it is planned to cover the outer surface of the drum with a thermal insulating composite material.

The required amount of heat to create the desired temperature in the dryer drum is determined by the expression [21]:

\[ Q = c \cdot \rho \cdot V \cdot (t_2 - t_1) \]  
(1)

where, \( c \) - specific heat of air at \( V = \text{const} \), \( j / \text{kg} \cdot \, ^\circ \text{K} \); \( \rho \) - density of air, \( \text{kg} / \text{m}^3 \); \( V \) is the volume of the drying drum, \( \text{m}^3 \); \( (t_2 - t_1) \) - the difference in temperature, \( ^\circ \text{C} \).

The required time for increasing the temperature in the drying drum can be determined by the formula:

\[ \tau = \frac{q}{N} \]  
(2)

where, \( N \) - is the power of the air heater, kW.

Let's compose the nomogram (graphs of the relationship between the power of the air heater, the temperature difference and the required time) for designing the drying drum of the device for drying grain crops. We use the following expression to do this:

\[ \tau = \frac{c \cdot \rho \cdot V \cdot (t_2 - t_1)}{N} \]  
(3)
2.2. Experimental studies.

It is known that the amount of heat absorbed or isolated when they heat bodies (samples) is heated, is proportional to the temperature change and their mass:

\[ \Delta Q = c \cdot m \cdot \Delta t \] (4)

where, \( c \) - is the proportionality coefficient, which is called the specific heat capacity and its value depends on the type of material.

In this experiment, the specific heat capacity of various materials in the form of granules (grains) is determined. In any case, the granules of the sample are weighed and heated to a certain temperature, and then filled with water at a certain temperature, the masses of which are also determined by weighing. After thorough mixing, due to the heat exchange of the sample and water, mixture reaches the total temperature. In this case, the amount of heat released by the sample:

\[ \Delta Q_1 = c_1 \cdot m_1 \cdot (t_1 - t_m) \] (5)

where, \( m_1 \) - mass of the pellet; \( t_1 \) - temperature of the pellet; \( t_m \) - temperature of the mixture; \( c_1 \) - is the specific heat capacity of the granule, which is equal to the amount absorbed by water:

\[ \Delta Q_2 = c_2 \cdot m_2 \cdot (t_m - t_2) \] (6)

where, \( m_2 \) - is the mass of water; \( t_2 \) - temperature of the water.

Here it is assumed that the coefficient of specific heat capacity of water is known, the temperature is equal to the temperature of steam. The value of the specific heat of the granules can be calculated from the experimentally measured values using the formula:

\[ c_1 = c_2 \cdot \frac{m_2(t_m - t_2)}{m_1(t_1 - t_m)} \] (7)

The vessel of the calorimeter also absorbs some of the heat released by the pellet. Consequently, the heat capacity of the calorimeter will be:

\[ c_k = c_2 \cdot m_k \] (8)

where, \( m_k \) - the water equivalent of the calorimeter.

Thus, the water equivalent of the calorimeter vessel is taken into account in the calculations. The amount of heat calculated by formula (9) is more accurate.

\[ \Delta Q_2 = c_2(m_2 + m_k)(t_m - t_2) \] (9)

And taking into account this formula (7) it is transformed to the following form:

\[ c_1 = c_2 \cdot \frac{(m_2 + m_k)(t_m - t_2)}{m_1(t_1 - t_m)} \] (10)

3. Results

3.1. Theoretical studies

The results of calculations performed with the aid of expression (3) can be represented in the form of table 1 and the graph (Fig. 1).

Table 1.

<table>
<thead>
<tr>
<th>Temperature difference( \Delta = t_2 - t_1, ^{\circ}C )</th>
<th>Time ( \tau, \ V \ sec(N=1) ) kW</th>
<th>Time ( \tau, \ V \ sec(N=2) ) kW</th>
<th>Time ( \tau, \ V \ sec(N=3) ) kW</th>
<th>Time ( \tau, \ V \ sec(N=4) ) kW</th>
<th>Time ( \tau, \ V \ sec(N=5) ) kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>52</td>
<td>26</td>
<td>17</td>
<td>13</td>
<td>10</td>
</tr>
<tr>
<td>10</td>
<td>104</td>
<td>52</td>
<td>34</td>
<td>26</td>
<td>20</td>
</tr>
<tr>
<td>15</td>
<td>156</td>
<td>78</td>
<td>52</td>
<td>39</td>
<td>31</td>
</tr>
</tbody>
</table>

Scientific Bulletin. Physical and Mathematical Research, 2019, №1

Published by 2030 Uzbekistan Research Online,
Figure 1. Nomogram for the selection of the power of the air heater.

\( a \)- for a hot-air heater with power \( N=1 \) kW; \( b \)- for a hot-air heater with power \( N=2 \) kW; \( c \)- for a hot-air heater with power \( N=3 \) kW; \( d \)- for a hot-air heater with power \( N=1 \) kW; \( e \)- for a hot-air heater with power \( N=5 \) kW.

We draw the dependence of the power of the air heater and the temperature difference (Fig. 2. Table 2).

To do this, we use the following expression:

\[
\Delta = t_2 - t_1 = \frac{\tau \cdot N}{c \cdot \rho \cdot V}
\]  \( (11) \)

**Table 2.** The results of the dependence of the power of the air heater and the temperature difference

| The power of the air heater \( N, \text{kW} \) | The temperature difference, \( \frac{\text{in} \cdot \text{V}^{-1} \cdot \degree \text{C}}{\text{sec}} \) is reached |
|---|---|---|---|---|
| \( 1 \) | 3 | 6 | 8 |
| \( 2 \) | 7 | 11 | 17 |
| \( 3 \) | 9 | 17 | 25 |
| \( 4 \) | 11 | 23 | 34 |
| \( 5 \) | 14 | 29 | 43 |

Figure 2. Dependence between the power of the air heater and the temperature difference in the drying drum. \( a \)-after \( t = 90 \) sec; \( b \)-after \( t = 60 \) sec; \( c \)-after \( t = 30 \) sec.
Here below we construct a graph of the relationship between the power of the air heater-\(N\) and the required time for increasing the air temperature-\(\tau\) in the drying drum by 5°C using the following expression (Fig. 3):

\[
\tau = \frac{5 \cdot c \cdot \rho \cdot V}{N}
\]  

(12)

The results of the calculation of the relationship between the power of the heater and the required time to increase the temperature of the air in the dryer drum

<table>
<thead>
<tr>
<th>The power of the air heater (N), kW</th>
<th>Required time (\tau) - (\cdot V) sec to increase the air temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>for 2°K</td>
</tr>
<tr>
<td>1</td>
<td>21</td>
</tr>
<tr>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 3.

3.2. Experimental studies.

For experimental determination of the coefficient of specific heat of rice, the experimental setup of Germany “LD Physics Leaflets” was used [22] (Fig. 4).

\begin{figure}
\centering
\includegraphics[width=\textwidth]{figure3}
\caption{Dependence between the capacity of the air heater and the required time to raise the temperature. \(a\) - for 2°K;\(b\) - for 5°K;\(c\)-for 10°K.}
\end{figure}

\begin{figure}
\centering
\includegraphics[width=\textwidth]{figure4}
\caption{Experimental installation "LD Physics Leaflets" 
1- heater; 2-tripod; 3-steam generator; 4- silicone hoses; 5-beaker; 6 - Dewar vessel; 7-scales (310g).}
\end{figure}
To test the (reproducibility) of the experimental setup, the specific heat capacity of granular materials of copper, lead, and glass was investigated. Making sure that the experimental data coincide with the literature data, the specific heat capacity coefficient of rice in a certain quantity was experimentally determined.

Before the start of the main experiment, we determine the mass, volume, density of standards (lead, copper, glass) and rice in a certain amount. To determine the mass of the samples, the scale “OHAUS CENT-O-GRAM MODEL 311” was used, as well as to determine the volume of the samples of the beaker with a volume of 150 ml. During the experiment, sample temperatures were measured with a NiCr-Ni thermocouple (thermal sensor) and a digital value was obtained with the help of “LEYBOLD”.

Samples of standards, rice and rice are applied.

The order of the experiment.

Install the heater-1 on a tripod-2, fill with water steam generator-3, carefully close the device and use silicone tubes-4 to connect it to the upper hose connector of the heater steam input. We fix the silicone tube in the lower inlet (steam outlet) to the hose connection of the heater and put the other end into the beaker-5. We make sure that the silicone hoses are securely fastened in all connections. Now we fill the sample chamber of the heater with sample pellets as close as possible and tightly close it with a stopper. We connect the steam generator to an electric oven, and then heat the pellet (sample) onto the heater for (80-85) minutes, passing a steam through them. During this time we determine the mass of the empty vessel Dewar-6 and then pour a certain mass of water in it. Close the Dewar vessel with the casing and insert a thermometer or a temperature sensor, respectively. We measure the water temperature. We open the lid of the Dewar vessel and move it aside, release the mesh with the samples in the Dewar vessel, drop the samples, the temperature of which is 100 °C, into the sample grid, close the lid and mix the samples thoroughly with water, until the water temperature ceases to decrease, mixture. In addition, we determine the mass of the sample. Thus, we repeat the experiment with other samples. The obtained experimental results are recorded in Table 1.

<table>
<thead>
<tr>
<th>The name of the sample (backfill)</th>
<th>Volume, ( \cdot 10^{-3} \text{ m}^3 )</th>
<th>mass ( m_1 ), gram</th>
<th>water mass ( m_2 ), gram</th>
<th>grams temperature sample ( t_1, ^\circ\text{C} )</th>
<th>Water temperature ( t_2, ^\circ\text{C} )</th>
<th>Mixture temperature ( t_m, ^\circ\text{C} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper</td>
<td>30</td>
<td>197,6</td>
<td>150</td>
<td>100</td>
<td>19</td>
<td>27,2</td>
</tr>
<tr>
<td>Lead</td>
<td>25</td>
<td>197,1</td>
<td>150</td>
<td>98</td>
<td>18</td>
<td>21</td>
</tr>
<tr>
<td>Glass</td>
<td>40</td>
<td>76,3</td>
<td>150</td>
<td>98</td>
<td>18</td>
<td>28,5</td>
</tr>
<tr>
<td>Paddy (sort of “Devzira”)</td>
<td>202</td>
<td>14,8</td>
<td>100</td>
<td>74,7</td>
<td>19,6</td>
<td>22,8</td>
</tr>
<tr>
<td>Paddy (sort of “Alanga”)</td>
<td>230</td>
<td>15</td>
<td>82,5</td>
<td>72</td>
<td>22,2</td>
<td>27</td>
</tr>
<tr>
<td>Rice (sort of “Devzira”)</td>
<td>269</td>
<td>15</td>
<td>100</td>
<td>72</td>
<td>22</td>
<td>24</td>
</tr>
<tr>
<td>Rice (sort of “Alanga”)</td>
<td>203</td>
<td>25</td>
<td>50</td>
<td>97</td>
<td>22,2</td>
<td>35,8</td>
</tr>
</tbody>
</table>

Based on the data obtained, sample densities were determined, the results of which are given in Table 5.

<table>
<thead>
<tr>
<th>Name of the sample</th>
<th>Copper</th>
<th>Lead</th>
<th>Glass</th>
<th>Paddy (sort of “Devzira”)</th>
<th>Paddy (sort of “Alanga”)</th>
<th>Rice (sort of “Devzira”)</th>
<th>Rice (sort of “Alanga”)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density of backfill, ( \text{kg} / \text{m}^3 )</td>
<td>6587</td>
<td>7884</td>
<td>1907</td>
<td>426</td>
<td>486</td>
<td>904</td>
<td>1060</td>
</tr>
</tbody>
</table>

Note: The bulk density of clay is (1400-1700), of natural moist sand (1500-1600) \( \text{kg} / \text{m}^3 \) [23].
It is known that the water equivalent \( m_w = 0.3 \text{g} \), the specific heat \( c_2 = 4.19 \text{kJ/(kg} \cdot \text{°K)} \).

Table 3 gives the values of the specific heat of substances (samples) calculated by formula (7) and their correspondence with the data given in the literature is satisfactory only for standards.

**Table 6.**

The experimentally determined values of the specific heat and the corresponding values obtained from the literature (at a moisture content \( W = 10\% \) for paddy and rice)

<table>
<thead>
<tr>
<th>Name of the sample</th>
<th>Experimentally determined value sample ( C_1 ), j / (kg \cdot °C)</th>
<th>The resulted value of the sample in the literature ( C_1 ), j / (kg \cdot °C)</th>
<th>Note (literary source)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper</td>
<td>357</td>
<td>367</td>
<td>[10]</td>
</tr>
<tr>
<td>Lead</td>
<td>144.4</td>
<td>133</td>
<td>[10]</td>
</tr>
<tr>
<td>Glass</td>
<td>670.3</td>
<td>656</td>
<td>[10]</td>
</tr>
<tr>
<td>Paddy(sort of &quot;Devzira&quot;)</td>
<td>1531</td>
<td>over 370</td>
<td>[1]</td>
</tr>
<tr>
<td>Paddy(sort of &quot;Alanga &quot;)</td>
<td>2458</td>
<td>over 370</td>
<td>[1]</td>
</tr>
<tr>
<td>Rice (sort of &quot;Devzira&quot;)</td>
<td>1166</td>
<td>782</td>
<td>[2]</td>
</tr>
<tr>
<td>Rice (sort of &quot;Alanga&quot;)</td>
<td>1862</td>
<td>782</td>
<td>[2]</td>
</tr>
</tbody>
</table>

4. Discussion

The amount of time necessary to reach the temperature of 283 °K to 308 °K inside the drying drum of the device for drying cereal products according to formula (1) is equal to:

\[
Q = 8,3710 \cdot 10^3 \cdot 1,247 \cdot V \cdot (308 - 283) = 260965,9 \cdot V
\]

The required time according to formula (2) for increasing the temperature in the drying drum from 10 °C to 35 °C is:

\[
\tau = 260965,9 \cdot \frac{V}{N}
\]

It is seen from Fig. 3 that for \( N > 3 \) the energy consumption for heating the air in the drying drum increases, and for \( N < 3 \) the required time for heating increases. Therefore, for the planned drying drum in particular, when drying the shawl, the optimum heater with a power of \( N = 3 \) kW is shown in the nomogram (Fig. 3). For a drying drum with a volume \( V = 1.09 \text{ m}^3 \) (cylinder radius \( R = 440 \text{ mm} \), cylinder height \( h = 1800 \text{ mm} \)) of an air temperature rises of 283 °K to 308 °K, with a difference of 25°K in the drying drum of Fig. 3, it is possible to determine the required time as follows: \( \tau = 87 \cdot V = 87 \cdot 1.09 = 94.8 \text{ sec} = 1.5 \text{ min} \).

Similar calculations can be made in Fig. 4. For example, the air temperature in the atmosphere is 25 °K. To dry the paddy in the drying drum, the temperature of 40 °K is required. With a temperature difference of 15 °K, a heating time \( \tau = (17.3 \cdot V) \cdot 3 = (17.3 \cdot 1.09) \cdot 3 = 56.6 \text{ sec} \) is required.

5. Conclusions

5.1. The value of the required time for creating a certain temperature in the drying drum increases with the increase in the drum size. When the power of the heater is increased, the required heating time for the creation of a certain temperature is reduced.

5.2. If the difference in temperature decreases, there is a reduction in the required power during drying, hence a reduction in energy consumption. Conversely, as the temperature difference increases, an increase in energy consumption is observed.

5.3. Given the types of dried grain crops, different temperature drying regimes are recommended. For example, the optimum drying temperature for rice is up to 35 °C, for peanuts up to 60 °C, etc. In such circumstances, it is recommended to select the required capacity of the air heater according to the nomogram.

5.4. Specific heat capacities of the samples were investigated from the material type and it was established that their values are much less than the heat capacity of water.

5.5. The correspondence of the specific heat values of the reference samples (lead, copper, glass) to the literature data provided in "Physical Notes LD" indicates that the experiment was performed correctly.
5.6. Specific heat capacity of embankment of paddy and rice of "Devzira" and "Alanga" varieties is determined within the accuracy limits of the error. According to the experimental data obtained, it is determined that the heat capacity of the grain mound depends on the type and grade of grain.

5.7. The specific heat capacities of embankment of paddy and rice of "Devzira" and "Alanga" varieties can be used for natural drying and for drying of small-sized, energy-efficient devices. The experimentally determined value of the heat capacity of the grain embankment makes it possible to calculate the amount of heat, the value of the latter determines the required energy for the process of grain drying in devices [24. P. 12].

References


References


Rayimjon Aliev, Andijan State University, Andijan, 170100, str. University, 129 (Uzbekistan). E-mail: agsu_info@edu.uz

Batirali R. Bekkulyov, Andijan machine building institute, Andijan, 170119, str. Bobur Shokh, 56 (Uzbekistan). E-mail: info@andmiedu.uz

Makhammadzhon T. Xalilov, Andijan machine building institute, Andijan, 170119, str. Bobur Shokh, 56 (Uzbekistan). E-mail: info@andmiedu.uz

Mualliflar ҳақида маълумот

Алиев Райимжон – техника фанлари доктори, Андижон давлат университети физика кафедраси профессори. E-mail: alievuz@yahoo.com

Беккуколов Ботирали Рахмонкулович – Андижон машинасозлик институти материалшунослик ва яниги материаллар технологиясига кафедраси тадцикотчиси. E-mail: botirali.bekkulov@mail.ru

Халилов Махаммаджон Тургунович – техника фанлари номзоди, Андижон машинасозлик институти физика кафедраси доценти.

2019 ышл 22 январда қабул қилинган

Scientific Bulletin. Physical and Mathematical Research, 2019, №1