Evaluation of Geothermal Grain Dryers: Case Study of Menengai Grain Dryer

Esther Njuguna
Geothermal Development Company,
P.O. Box 100746-00101 NAIROBI,
KENYA
enyambura@gdc.co.ke; esta.nyambura@gmail.com;

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ABSTRACT
Alternative applications of geothermal energy, also known as direct use have over the years gained popularity globally. One of the major applications is drying where geothermal heat is used to raise temperatures in the environment of a product with an aim of reducing their moisture content. Different types of dryers are designed to utilize geothermal energy depending on the product to be dried. In order to maintain a quality product after drying, a good dryer design with optimal drying parameters must be emphasized. Different geothermal dryers have been constructed and used in different countries to dry different agricultural products. Among these countries is Kenya whose first geothermal dryer was constructed during the colonial times as a community project, and has since been used in small scale to dry pyrethrum and maize in the Eburru geothermal region. Kenya has recently registered a new milestone after Geothermal Development Company (GDC) installed a modern semi-commercial batch geothermal grain dryer at the Menengai Geothermal Field. This paper explores the various types of geothermal grain dryers, their design, technical parameters and operational costs in comparison with the new grain dryer in Menengai with an aim to establish an optimal design and size of a grain dryer.

1. Introduction
Drying is defined as a mass transfer process consisting of the removal of water or another solvent by thermal means from a solid, semi-solid or liquid. It is the phase of the post-harvest system during which the product is dried to a safe moisture content level. Its main objective is to reduce the moisture content to allow for a longer storage period safely. It also reduces the weight and volume making packaging, storage and transportation easier (Kavark Akpinar
et al., 2006). A lower moisture content also allows favorable conditions for further processing of most products. Drying is a major operation in the food industry consuming large quantities of energy accounting for 10-25% of the total energy in processing (Mujumdar, et al, 2000). Industrial drying processes, must therefore be optimized to reduce the moisture content at minimum costs.

Agriculture is the main source of national income for most developing countries, and forms a basis for food and nutrition security. It also provides raw materials for industrialization. Most food products from the Agricultural sector require to be dried and stored. Some of these products are seasonal, hence largely available and cheap during the harvesting season, then become scarce and expensive during the off season. Good preservation methods must therefore be employed to ensure availability of the food crops during all seasons. One of the preservation methods is drying. Apart from removal of water, drying must also take care of preservation of the structure and content of the product to ensure that their quality is maintained. Many drying techniques have emerged in the recent decades and a careful selection of one that will optimize the drying conditions is a significant consideration (Gunathilake, et al., 2017).

In most drying techniques, air is used as the medium for movement of the moisture in the food crop. This can be done naturally using the sun, or artificially using dryers. There exist numerous types of artificial dryers all of them aiming at providing hot air around the food crop in order to reduce its moisture content.

Moisture content is defined as a percentage of the water contained in a given sample of grain in comparison with the total weight of the sample. It is expressed either as wet basis or dry basis calculated as follows:

\[ M_{wb} = \frac{W_w}{W_w + W_{dm}} \times 100 \]  

\[ M_{db} = \frac{100 \times M_{wb}}{100 - M_{wb}} \]  

where \( M_{wb}, M_{wb}, W_w \) and \( W_{dm} \) are moisture content on a wet percent basis, moisture content on a dry percent basis, weight of water and weight of dry matter respectively.

2. Artificial Dryers

Artificial drying has advantages over the natural drying mostly when large quantities of grain are harvested with a high moisture content over a short period of time. Grains are, therefore exposed to a ventilation of heated air in a controlled environment termed as a dryer (Gunathilake, et al., 2018). When air is heated, its capacity to absorb moisture increases. There are two main types of grain dryers; static or discontinuous dryers, mostly suitable for small scale applications, and continuous dryers, which are more expensive and more suitable for medium and large scale applications. A dryer is made of the following main parts:

- The body, which holds the grain when drying
- The source of heat
- The ventilator, mostly a fan or blower

The method of introduction of heat during drying greatly affects the process of drying. For convective drying, the temperature, streaming velocity and relative humidity of the drying media are necessary parameters. Chamber dryers are normally characterized by uneven
drying due to partial and unevenly distributed temperatures in the different regions. They also have a disadvantage in that they require a heavy supply of labour for manual work. Conveyor dryers have a chamber where the drying material is placed and moves on the loading strip, while tunnel dryers have doors simultaneously opened to enable loading and unloading of the material for drying. Drum dryers are suitable for beer and sugar refuse, grains and food plants. They enable moving and mixing of the material, and could contain different compartments to improve on the drying of the material. Another type of a dryer is pneumatic, where the disperse material is dried while in transport. These dryers consume more electricity, and are more ideal for grains, chopped dairy foods and leaves.

2.1 Geothermal Dryers

There exist numerous examples of dryers utilizing geothermal as a source of heat across the world. Heat is mined from hot water or steam directly from a geothermal well or from waste heat from geothermal power plants (Vasquez et al., 1992) through heat exchangers. A heat exchanger must, therefore, be incorporated in the manufacture of the dryers since geothermal fluids are most often not used directly due to their scaling and corrosive nature. Examples of geothermal drying are in: tomato and cotton drying in Greece, chili and garlic drying in Thailand, pyrethrum and maize drying in Kenya, bean and grain drying in Indonesia, onions in the USA and fish drying in Iceland.

![Figure 1: Geothermal dryer in Eburru, Kenya](image)

A few examples of geothermal grain dryers are discussed below with some of their characteristics:

2.1.1 Drying of rice in Kotchany-Macedonia (Popovski, K., et al, 1992)

The 10 tonnes per hour capacity cross-flow unit (Figure 2) utilizes water from a low rate of scaling and corrosion source at 75°C. Moisture content of the rice is reduced from 20-14% using air at 35°C. Geothermal water of between 50°C and 75°C is used to heat the air through heat exchanger. Temperature of the heated air is maintained at 40°C to protect the rice from cracking. This dryer has proven very effective since it is used in a period of the year when greenhouses are not heated, hence lowering the competition for heat energy.
2.1.2 Bean and grain drying in Indonesia

In the Kojamong geothermal field of west Java, geothermal steam from a well with a temperature of about 160°C is used to heat air in a heat exchange process for drying grains. Air flow velocity is estimated at between 4 and 9m/s while drying is performed at temperatures of 45°C to 60°C. Grains last in the dryer for an amount of time influenced by their original moisture content (Nguyen et al., 2015).

2.1.3 Grain, fruit and vegetable drying in Guatemala

In Guatemala, a drier with a capacity of 0.5MWt capable of drying grains, fruits and vegetables is complete. Its energy consumption is estimated at 12.094 TJ/yr with a capacity factor of 0.8 (Vasilevska-Popovska, 2003).

2.2 The Menengai Geothermal Grain Dryer

In October and November, 2019, Geothermal Development Company (GDC) in collaboration with the Icelandic International Development Agency (ICIEDA) installed a semi-commercial batch grain dryer on the Menengai well 03 (MW 03) site which also hosts another four demonstration projects for geothermal energy. Table 1 below outlines the features of the dryer:

<table>
<thead>
<tr>
<th>Feature</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intake bay</td>
<td>1.06m³</td>
</tr>
<tr>
<td>Wet bin</td>
<td>12 tonnes</td>
</tr>
<tr>
<td>Drying Chamber</td>
<td>6 tonnes</td>
</tr>
<tr>
<td>Dry bin</td>
<td>8 tonnes</td>
</tr>
</tbody>
</table>
Heating and electrical system

Entailing the radiator, motors, suction pump, grain conveyors and temperature gauges

The dryer also consists of several motors which use electrical power as indicated below:

<table>
<thead>
<tr>
<th>Electrical Item</th>
<th>Horsepower Rating</th>
<th>kW Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suction pump</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Hot water Pump</td>
<td>3</td>
<td>2.25</td>
</tr>
<tr>
<td>Elevator Motor</td>
<td>3</td>
<td>2.25</td>
</tr>
<tr>
<td>Intake Motor</td>
<td>3</td>
<td>2.25</td>
</tr>
<tr>
<td>Auger Motor</td>
<td>3</td>
<td>2.25</td>
</tr>
<tr>
<td><strong>Total electrical load</strong></td>
<td><strong>16</strong></td>
<td><strong>12</strong></td>
</tr>
</tbody>
</table>

The dryer utilizes about 0.15m³/min of hot water introduced at between 55°C and 65°C. Water is heated through heat exchange using hot geothermal fluids from Menengai well 03 (MW 03) or (MW 12) flowing at about 90°C. Ambient air is then heated to between 40°C and 60°C which is ideal for drying of most grains available in Nakuru, Kenya where the dryer is located. Preliminary tests performed on drying of grains are recorded in Table 2 below:

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Type of grain</th>
<th>Quantity dried (tons)</th>
<th>Initial moisture content (%)</th>
<th>Final moisture content (%)</th>
<th>Time taken for drying (hrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Wheat</td>
<td>6</td>
<td>20</td>
<td>15</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>Maize</td>
<td>8.5 (in two batches)</td>
<td>20</td>
<td>14</td>
<td>4</td>
</tr>
</tbody>
</table>
Since the dryer is relatively new, more tests will be performed on the dryer using different types of grains in addition to maize and wheat, such as beans and canola in order to ascertain the optimal drying parameters for each grain type using this dryer. Preliminary tests have also shown that geothermal drying is the most favorable in terms of cost, reliability and time in comparison to the modes of drying applied by farmers and the industry in Nakuru. For instance, it costs approximately Kshs. 50 per drop of moisture content to dry a 90kg bag of maize in the sun, not considering the numerous disadvantages of this method including contamination and unreliability of the weather, and Kshs. 45 for the same using Industrial Diesel Oil, which also poses a big threat to the atmosphere due to pollution. Currently, GDC intends to charge about Kshs. 15 per drop of moisture content for every 90kg bag of grain using the dryer in Menengai. It has already been established that there is plenty of a variety of grains around the dryer location, and are available all year round, making this dryer a game changer in the grain farming and industry. The largest quantity of grain, however is maize which is harvested during the peak of short rains in Kenya (October and November), and this dryer will cause a big impact in saving the drying challenges of farmers and the grain handlers in Nakuru.

The installation and testing of this dryer has not come without challenges. As soon as the first two tests were done on the dryer, Kenya was faced with the COVID-19 pandemic, causing a halt in the testing of the dryer. Further tests on the dryer are already in plan, and the results will be published for reference. These tests will also form a reference point for comparison of drying costs using the conventional sun drying, the use of Industrial Diesel Oil (IDO) and the new geothermal drying technology. Modifications on the dryer will also be done to reduce its electrical consumption for instance by ensuring grain from the drying chamber flows into the storage (dry) bin by gravity.

The Menengai geothermal dryer will prove the most preferred mode of grain drying due to its advantage in terms of technology, time and cost. Geothermal is green and reliable across seasons, hence the dryer can be used even during rainy seasons when methods like sun drying are impossible. Grains are dried in a batch, saving time and reducing on handling challenges and contamination that come with natural sun drying. The cost of drying is also much lower than the other methods of drying since the heat used by the dryer is a by-product of the energy conventionally used for electricity generation.

2.3 Conclusion

Different types of dryers have been constructed and put to use in grain drying across the world, and have proven better than the conventional methods of drying. It is noted that for all dryers, the amount of time taken to dry the grain is determined by the original moisture content of the grain being dried and the method of introduction of the hot air for drying. Different grain types also require different drying parameters like temperature and the air flow rate. If the drying temperature is low, the grain may not dry properly and may rot, while very high temperatures could cause cracking and case hardening, and sometimes may kill the life in seed grain. In all the dryers discussed in this paper, heat exchange is part of the dryer construction consideration, since most geothermal fluids are corrosive and scaling in nature and cannot, therefore be used directly.

Geothermal drying has, however also been proven beneficial in drying other products like sea weed, fish, meat fruits and vegetables.
REFERENCES


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