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DESIGN OF GEOTHERMAL DRYERS FOR FOOD PRODUCTS IN TANZANIA

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ABSTRACT

Around 80% of the self-employed people in Tanzania are working in the agricultural sector including livestock keeping and fisheries. A wide variety of crops (vegetable, fruits and grains) and animal products are produced in the country but with great potential for further expansion. Processing food using renewable energy might be a cheaper option compared to oil or gas which are too expensive to be afforded by small farmers managing 2 to 10 acres and would contribute to the protection of the country from environmental pollution. Geothermal heat is one of the energy resources available in Tanzania and it is not yet being fully utilised as it is also the case for the biomass, hydro, solar, uranium, natural gas and coal. : It is advantageous to use this energy resource for drying raw materials from agriculture and fisheries because it prevents food from being damaged in the value chain before it reaches consumers.. Several studies have been conducted and highlighted the causes for the losses, some of which are also highlighted in the present study. With the result of this study are the design of two sets of the geothermal dryers, drying two food products commonly available in the country that differ in water activity, moisture content and drying processes. The results support the country's Development Vision 2025 of moving from a developing into middle income country and support the SDG goal of the United nations (UN) to reduce food waste and loss by 50% worldwide by 2030.

1. INTRODUCTION

Drying is one way to preserve food to elongate its life shell by removing the water activity that creates the favourable environment for mould, fungi, microorganisms or enzymes and chemical reactions that result to food spoilage. Normally relatively small amounts of water are removed thermally by air from the material or mechanically by pressing, centrifuging etc. (Geankoplis, 1993). Traditionally, open sun drying has been mainly practised in Tanzania and other sub Saharan African countries together with open fire roasting using firewood despite of its setbacks. The food product takes longer time to dry with the risk of being contaminated or does not dry properly. Also, the temperature in order to optimally maintain the taste of the food and to protect it from loss of nutrients cannot be realised. The improved open drying using solar as seen in Figure 1 and drying using firewood have been researched repeatedly and some of the environmental and health risks encountered by the open sun drying and open fire could be reduced. Recently, technological improvement has been made to keep the heat at a specific temperature and to control humidity and air flow. The heat source can be fuelled by oil, natural gas or renewable energy sources such as solar, geothermal etc. Indoor drying has been very successfully applied in developed countries such as Iceland that uses geothermal dryers for the drying of fish. It is advantageous that the drying can be conducted throughout the year yielding high amounts of food products with good quality, free from contaminations with insects or bacteria and that it utilises the available local resource (Arason, 2003).

The objective of this report is to present improved technology of indoor drying by designing geothermal dryers (heat source from renewable energy) as an alternative solution to address the challenge of food losses in the agricultural, livestock and fisheries sector with the availability of the geothermal resource potential in Tanzania. According to research made by Abass et al. (2014) and Bola et al. (2013), losses are encountered due to change of weather, poor transportation infrastructure, limited storage facilities, unawareness of the proper post harvesting methods, manual labour extensive processing resulting in low yield and improper drying. According to Dube et al. (2018), in 2016 Tanzania incurred net imports of 79% of preserved tomatoes from China while importing about 50% of its demand for marmalade, nut puree, nut pastes other than citrus, fruit jellies and jams from India and 30% from Kenya. The processing industry sector for small holder farmers has been growing slowly due to lack of finance and technological equipment. The local improved method of outdoor are sun drying of dagaa (*Rastrineobola argentea)* where products are placed on the cages together with further improvement of the outdoor solar drying (Figures 1 and 2) and the designed solar cabinet shown in Figure 3.

FIGURE 1: Outdoor sun drying of dagaa in Tanzania (photo by Arason, 2012)

FIGURE 2: Improved outdoor sun drying of dagaa on the rack in Tanzania (Ministry of Agriculture Livestock and Fisheries, 2016)

2. GEOTHERMAL POTENTIAL IN TANZANIA

Tanzania is located on the East African Rift System and has a geothermal resource potential of more than 5000 MW that can contribute to economic development while keeping carbon emissions low. The geothermal resources range from low, medium to high temperature systems and some of the prospects where surface studies have already been conducted are discussed below (Kajugus et al., 2018).

FIGURE 3: Small scale indirect solar batch dryer (Match Maker Associates, 2008)

2.1 The Ngozi geothermal prospect

The Ngozi geothermal prospect is located within the Rungwe Volcanic Province (RVP) in the southwest of Tanzania in the Mbeya region. Detailed surface studies have been conducted and reveal a reservoir temperature of 232 ± 13°C, total dissolved solids (TDS) of 15,800 ± 2300 mg/kg (mainly Na-Cl composition) and a P_{CO2} of 15 ± 4 bar as shown in the conceptual model in Figure 4. In the study, five locations for test drilling have been proposed. Environmental permits for the drilling have already been obtained and funding has been approved by the Geothermal Risk mitigation facility (GRMF) that will

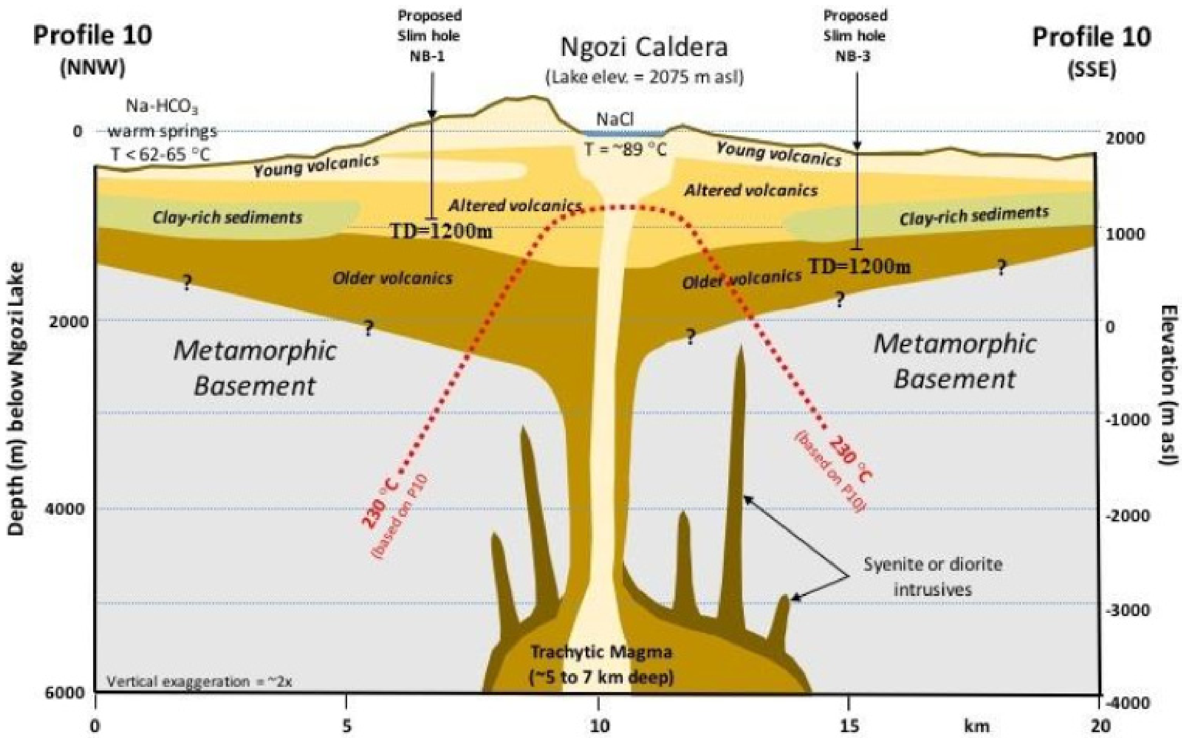

FIGURE 4: Conceptual modal for the Ngozi geothermal system (Kajugus et al., 2018)

co-finance the project with the government of Tanzania. The expectation is to start the drilling during the financial year of 2019/20, hence the mobilization of funds is ongoing (Kajugus et al., 2018).

2.2 The Songwe geothermal prospect

The Songwe geothermal prospect is located northwest of the Ngozi prospect in the Songwe region. Detailed surface studies reveal that Songwe has a low- to medium-temperature resource with a temperature of 112 ± 16°C. Further studies were made and recommended the drilling of fourteen temperature gradient holes (TGH) to identify the most promising area for test drilling as shown in Figure 5. Also, further prefeasibility studies were conducted considering direct use applications and it shows

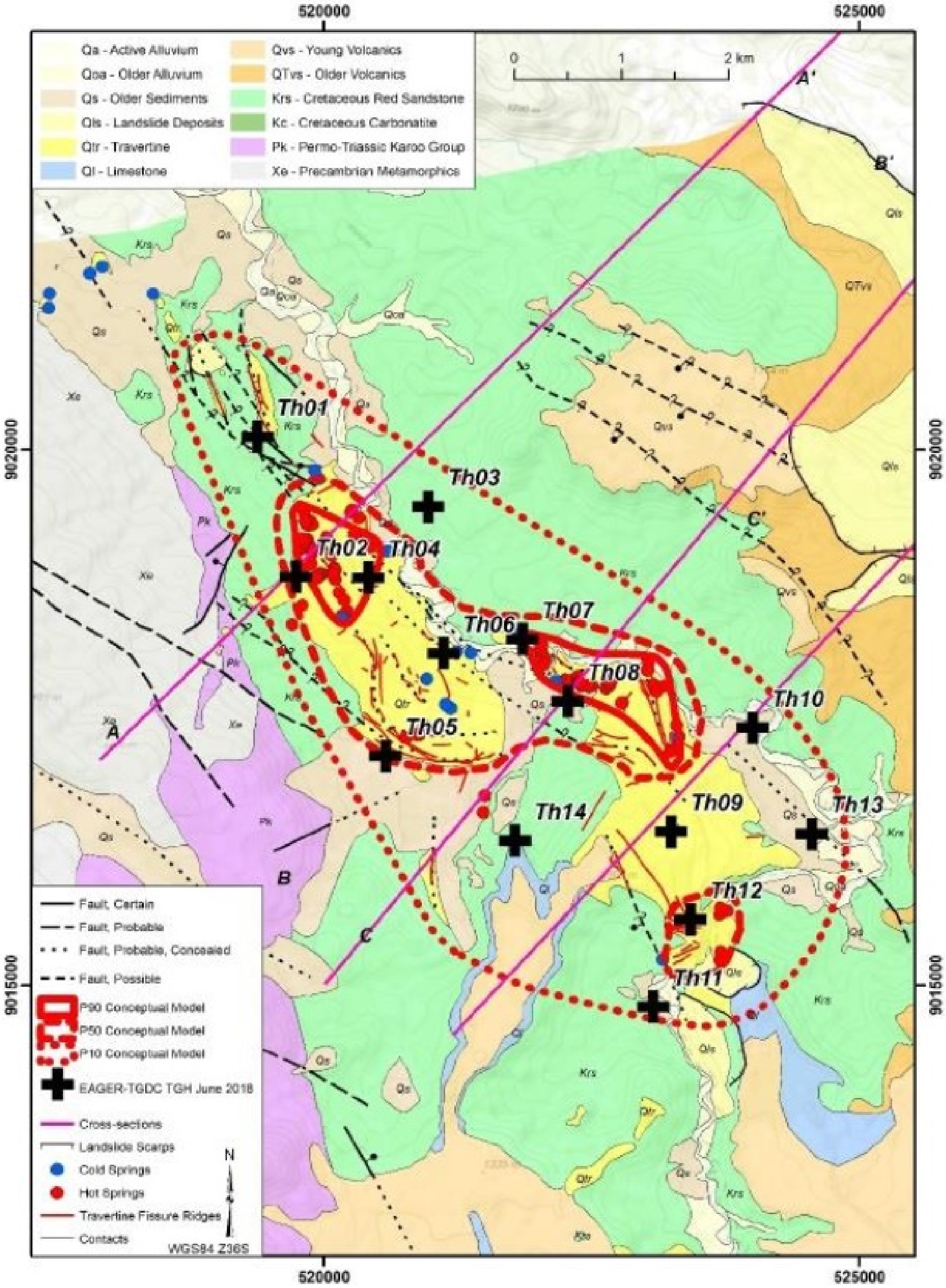

FIGURE 5: Conceptual model of Songwe and TGH locations (Kajugus et al., 2018)

that the conditions are favourable for drying of agriculture crops, tourism and aquiculture (Kajugus et al., 2018).

2.3 The Kiejo – Mbaka geothermal prospect

The Kiejo-Mbaka geothermal prospect is in the southern part of the Rungwe volcanic province where the Ngozi, Rungwe and Kiejo volcanoes are situated in the southwest of Tanzania in the Mbeya region. Several studies have been undertaken whereby the recent study revealed that Kiejo - Mbaka is a medium-temperature geothermal system based on the assessment of water and gas geothermometric with a reservoir temperature of 140°C in Figure 6 (Kajugus et al., 2018).

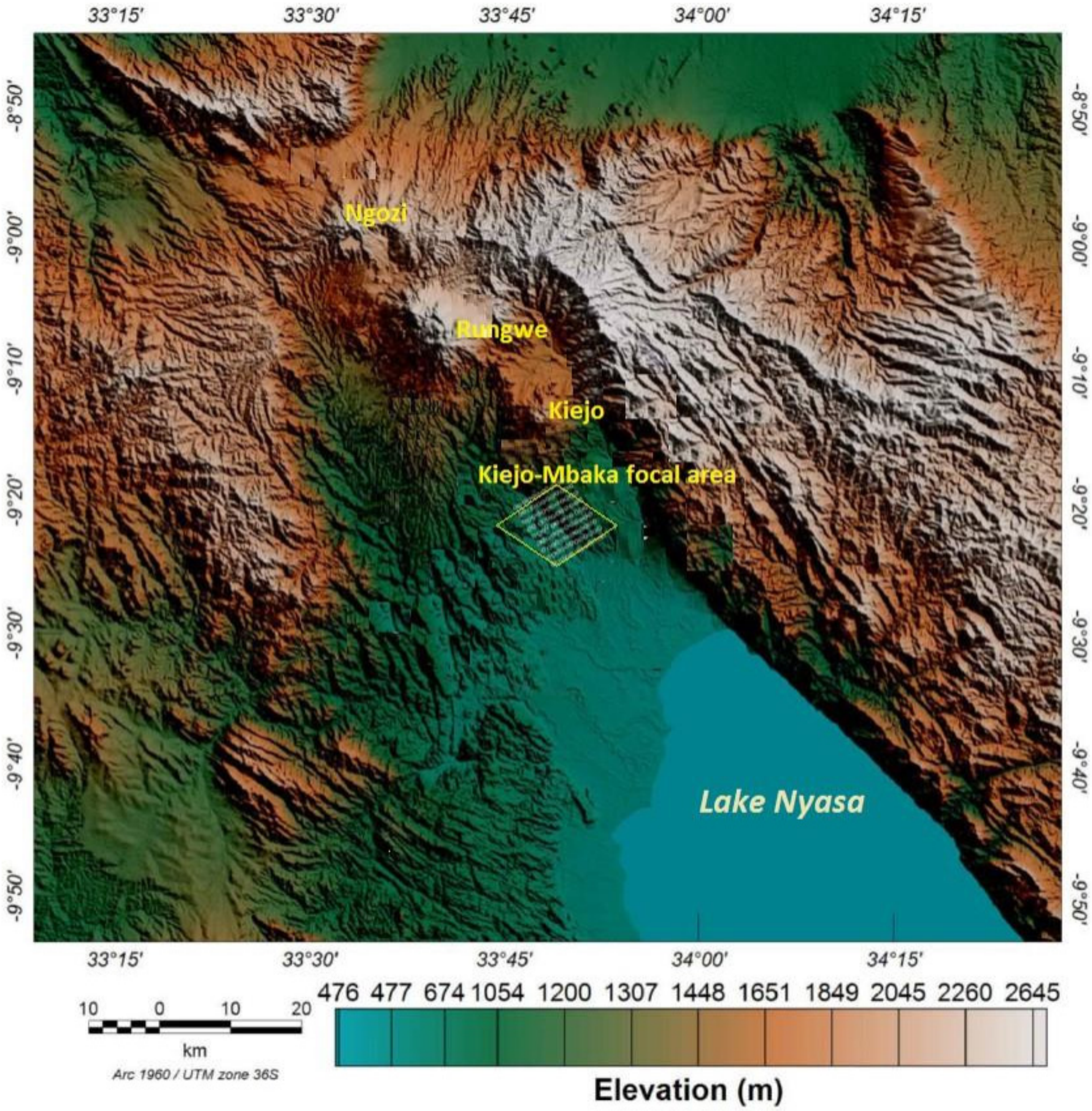

FIGURE 6: 3D topography view of Kiejo Mbaka volcano in the Rungwe volcanic province (Kajugus et al., 2018)

2.4 The Luhoi geothermal prospect

The Luhoi geothermal prospect is located at the coast as seen in the geological map (Figure 7) in the southern part of East African Rift System (EARS). The detailed surface studies show that this is a low-temperature geothermal system with reservoir temperatures ranging from 95 to 145°C and suitably for direct use applications and binary power generation (Kajugus et al., 2018).

The four prospects described above are ready for drilling to confirm the resources while the task of mobilizing funds and formulating legal and regulatory law governing the geothermal development is

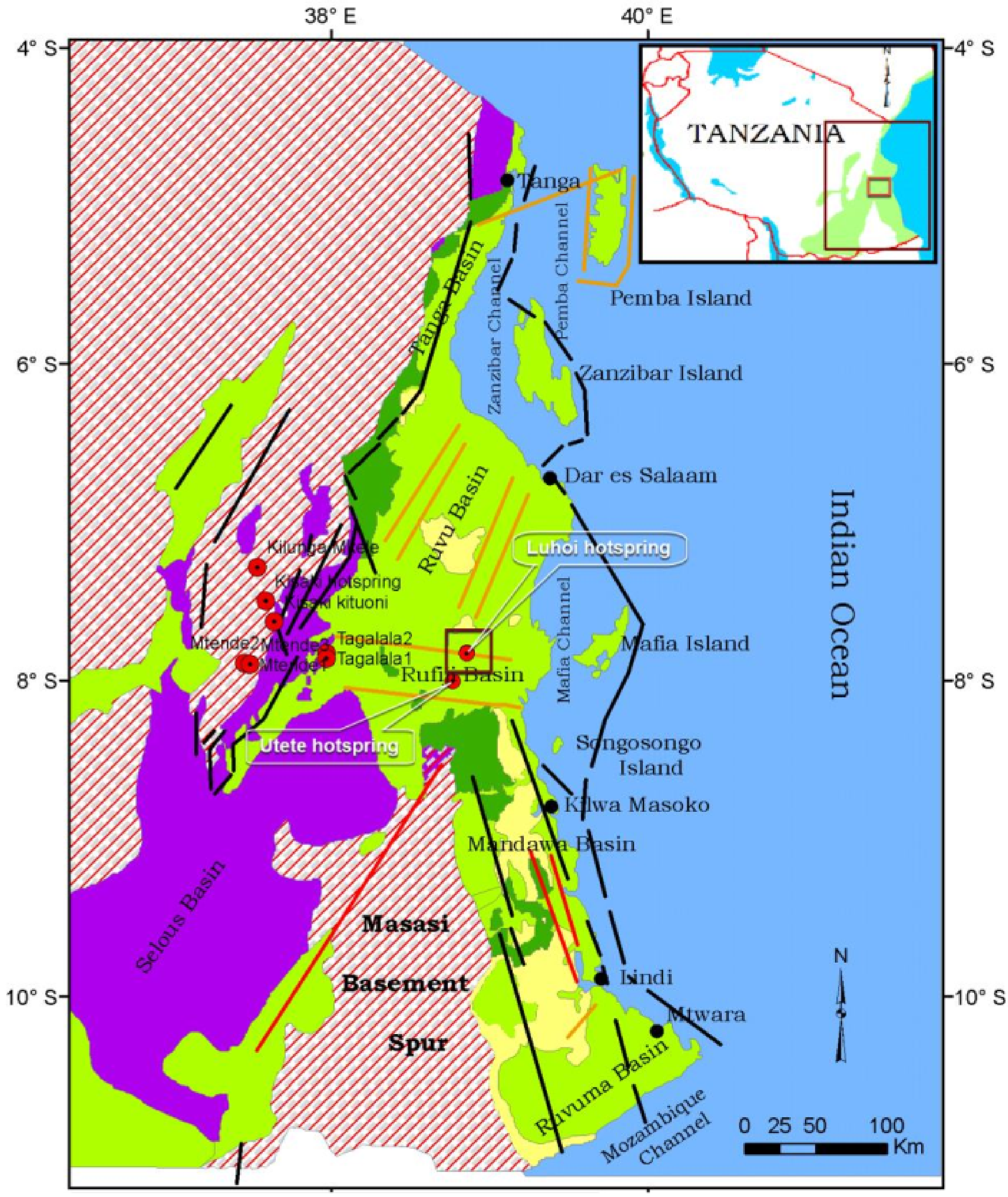

FIGURE 7: Geological map of Luhoi (Kajugus et al., 2018)

pending. After resource confirmation the resources will be evaluated depending on their temperature and pressure of the fluid considering its chemical composition and flow, the distance that the fluid will be transported and the possibilities of integrating the resource with other applications such as green houses, swimming pools etc. If the system is a high temperature system, it can be utilised for both electricity generation and direct use applications depending on the temperature of the waste brine from the geothermal power plant. Also, if the resource is low temperature, electricity generation is possible using a binary system together with direct use applications. Among the four prospects ready to drill for resource confirmation, the three prospects Ngozi, Songwe and Kiejo - Mbaka are in the same region in southwest Tanzania with subtropical highland climate, humid summers and dry winters.

3. RAW MATERIALS

The raw materials to be dried are close to the geothermal resource and therefore it can be advantageous to build a geothermal drying station, as shown in Figure 8.

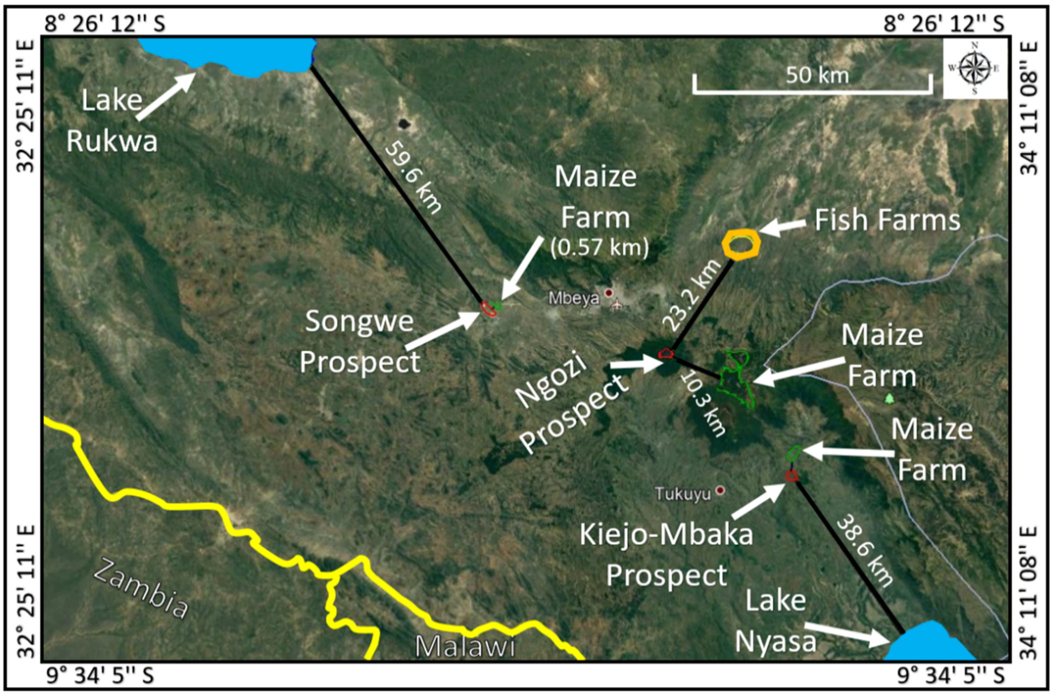

FIGURE 8: Location and distance of the fish and maize farms from the geothermal prospect (Google Earth Pro, 2018)

3.1 Food

Food is defined as any material that is being consumed by humans or animals to provide nutrition. It is usually of animal or plant origin. Drying is a common and important method in the food processing industry. In Tanzania a variety of food crops are grown such as maize, wheat, millet, beans, cassava, potatoes, avocados, bananas, mangoes, oranges etc. Common animal products are meat, fish, chicken, milk, eggs etc. The foods differ from each other depending on the amount of water activity. Some contains water activity of around 98% water while others contain around 30% water. Due to such differences, this paper has selected two food products for drying that will allow us to show exactly how the drying processes takes place within food with high or low water activity. Fish is selected as an example of a product with high water activity (close to 80%) which is dried in two steps while maize, a product with low water activity (close to 30%) is dried in one step (Arason, 2019). Some fruits and vegetable contain close to 98% water.

3.2 Maize product

Maize (white not the yellow type) is being consumed in Tanzania and provides 80% of dietary calories as well as more than 35% of protein and the total annual consumption per capita is 135 kg. This makes maize/corn the main staple grain in the country (Mtaki, 2018) which is consumed as starch in beer, grits, porridge and pastes and eaten (before it dries) after being boiled, roasted, baked etc. (Bola et al., 2013). According to Sheahan and Barrett (2017) and Kaminski and Christiaensen (2014), reported that food losses in sub Saharan Africa by the farmer is 3.7% in Uganda, 4.7% in Nigeria and Ethiopia, 6.2% in Benin and 6.9% in Tanzania. Figure 9 shows the harvest season of maize in June and July. Grains such as maize must be dried to 10 to 15% moisture content, with 14% moisture being suitable for short term storage and around 12 to 13% moisture for long term storage. Optimal drying temperature for maize (white corn) which is available in Tanzania (Figure 10) is 43°C and over drying can result in germination loss (Reykdal, 2018). When the maize product has a water activity (a_w)of less than 0.6 and the moisture content is below 12%, then fungi and microorganism growth is inhibited except for insects that are metabolically able to produce the water for their food which can survive and grow until an equilibrium relative humidity (ERH) falls below 35% is showed in Figure 11 (Bradford et al., 2018).

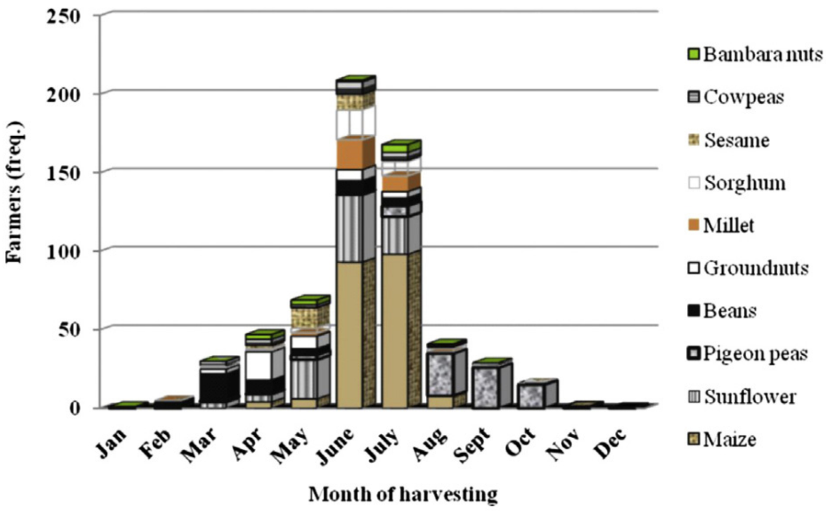

FIGURE 9: Harvest season for selected crops (Abass et al., 2014)

FIGURE 10: White corn in Tanzania (Sew4home, 2019)

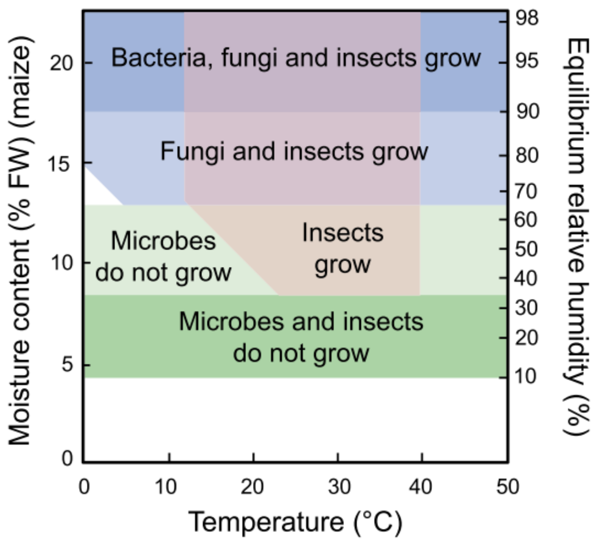

FIGURE 11: Moisture content or equilibrium relative humidity (ERH = a_w * 100%) with temperature at which bacteria, fungi and insect can grow (Bradford et al., 2018)

3.3 Fish product

Fish provides around 30% of the animal intake and the average consumption is around 7 to 8 kg annually. This percentage is low compared to the global average consumption which was 20 kg per capita in 2014 due to the annual population increase of 2.7% and the lack of supply (MALF, 2016). Around 1% of the fish is produced using aquiculture method while 85% is fished in inland waters and 14% come from marine fishing. Post harvesting loss occurs especially during rainy seasons where much of fish is destroyed and can only be used for animal consumption. Traditionally, fish are processed by women by salting, smoking and frying at home. Therefore, the fish is dried at a temperature of 28°C until the moisture content has been reduced from initial 80% down to around 10% moisture (Arason, 2019). Other challenges are limited storage facilities, limited access to power (electricity), and market competition (Rukanda, 2016). Mgebuka is a common type of fish found in Tanzania, Figure 12.

FIGURE 12: Mgebuka fish from Tilapia family found in Tanzania (Instagram Stats, 2019)

4. GEOTHERMAL DRYING

Geothermal drying is one of the direct use applications of geothermal resources that is utilised in developed countries. Therefore, it can support Tanzania's vision to become a middle-income country by 2025. For example, the drying of cod heads in Iceland using geothermal energy is more economic than the use of heat pumps, electricity or oil (Arason, 2003). According to the Lindal diagram in Figure 13 below, direct use applications can utilize water at temperatures from around 10 to 150°C. For drying the temperature of the geothermal hot water (brine) can range from 80 to 100°C with the inlet temperature in the dryer being dependent on the food to be dried, i.e., fruits, vegetable, grains or animal products, the humidity of the surrounding, the humidity in the dryer, the size of the drier and the time required to complete the drying process.

4.1 Drying mechanism

Drying is described as the removal of water that would enable the growth of microorganism or allow chemical reactions to take place in the food. It can be expressed that the water content on wet or dry basis whereby on the dry basis is always higher than on the wet basis (Wilhelm et al., 2004). The higher the water activity the higher the risk of the food being spoiled depending on the type of food product. Water activity lower than 0.3 allows oxidation reactions to take place while microorganisms become inactivated at a water activity of 0.7 or below (Sokhansanj and Jayas, 2006). Therefore, food is microbiologically stable at a water activity of less than 0.7 (best in the range of 0.5-0.6) together with proper packaging that will retain and maintain the colour, structure and flavour of the product (Saravacos and Kostaropoulos, 2016). When the moisture is below 10 % the microorganisms are not active but attaining a moisture content between 5-9% (a_w less than 0.6) is needed to preserve the flavour and nutrition value of the food (Geankoplis, 1993).

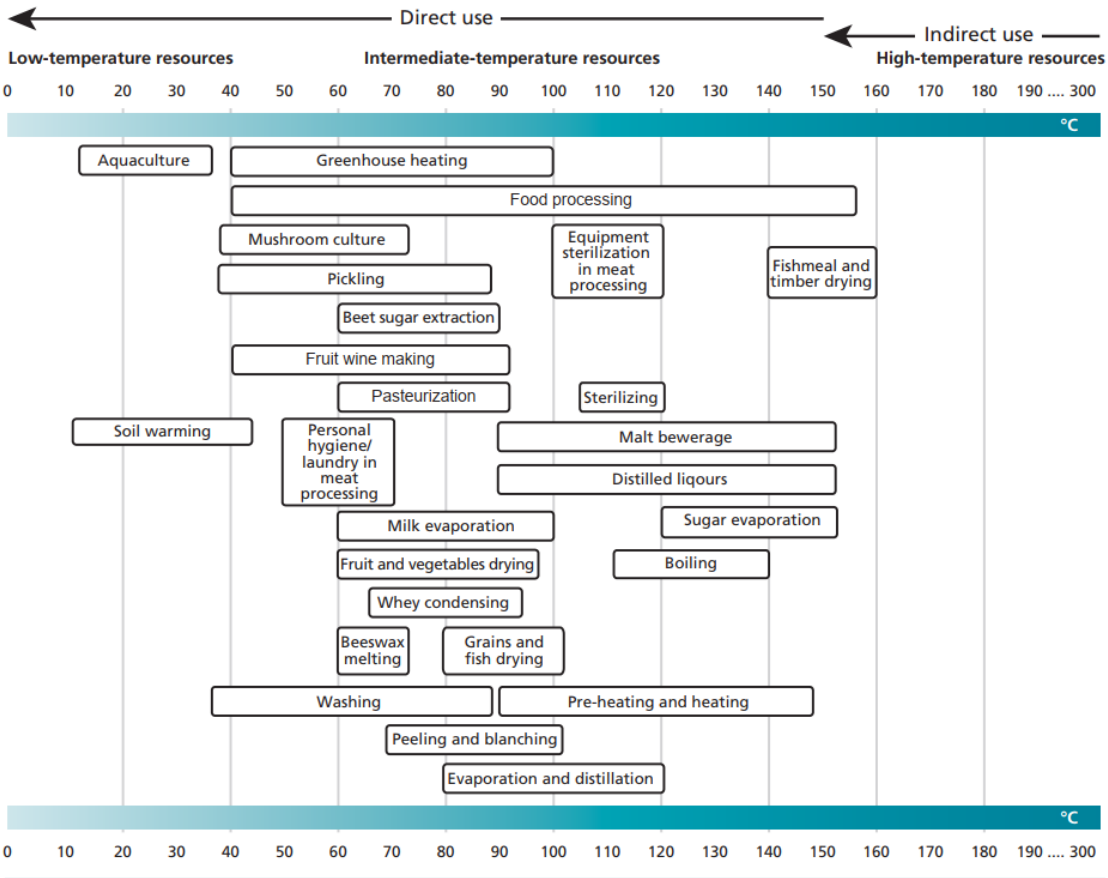

FIGURE 13: Lindal diagram with temperature range for geothermal applications (Nguyen et al., 2015)

4.2 Types of dryers

Driers are classified according to the product that is to be dried, the temperature and pressure being set in the drier (high, medium or low) and how the heat is supplied to dry the product (Mujumdar, 2006) but dryers can also be described according to the temperature of the media to dry whether it is ambient, low temperature or high temperature. Selected types of dryers and their applications are described below.

4.2.1 Solar dryer

This is a widely known method where the air is heated by the solar collector either naturally or forced. The air dries the product by natural convection or by a fan that is used to blow the heated air over the product to enable faster drying of the product. It is mostly used in hot regions where the average duration of sunshine is 7 hours per day with an energy flux of 0.6 kW/m² and is normally used to dry agricultural products such as fruits, vegetables and grains. Figure 14 shows a sample of a solar dryer.

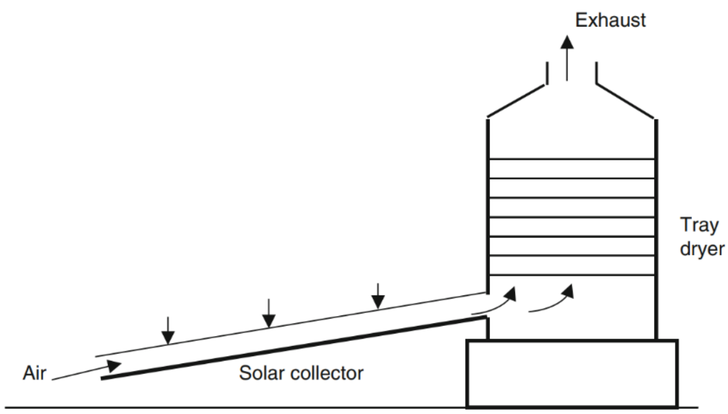

FIGURE 14: Sample of a solar dryer (Saravacos and Kostaropoulos, 2016)

4.2.2 Tunnel dryer

The inlet air goes through the inlet door (1, see Figure 15) and passes through the heat exchanger (2) where it is warmed and evenly distributed by a fan (3) to flow through the cabinets that contains shelves of the product to be dried. The hot air absorbs the evaporated water from the food product, so when the hot air is cooled again its humidity increases. After passing through the cabinet with the shelves (4), some of the water exits through the exhaust door (6) while some is recirculated through the valve (4) to the drier together with the inlet air and heated again. The cycle repeats to certain number of times until the drying process is complete. This type of dryer is being used for fish drying as a primary dryer as shown in Figure 15 where the surface of the fish is dried. Then the fish undergoes a secondary drying process in a container dryer described in Figure 16 below (Arason, 2003).

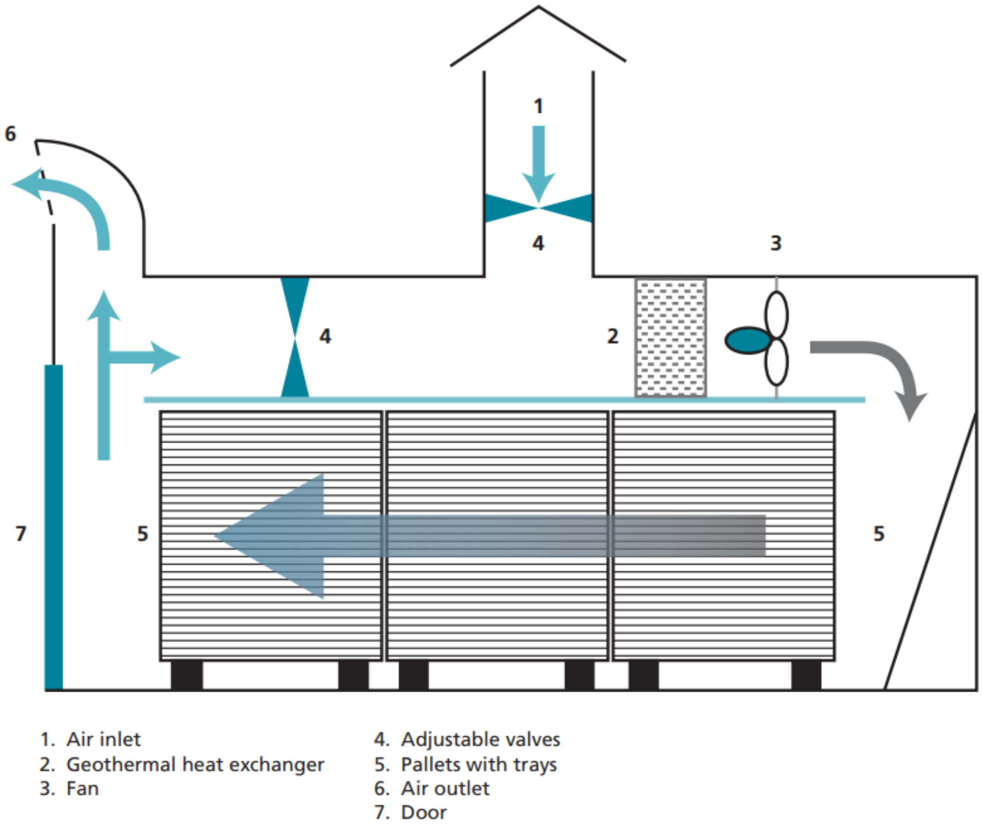

FIGURE 15: Example of tunnel cabinet dyer for primary drying (Nguyen et al., 2015)

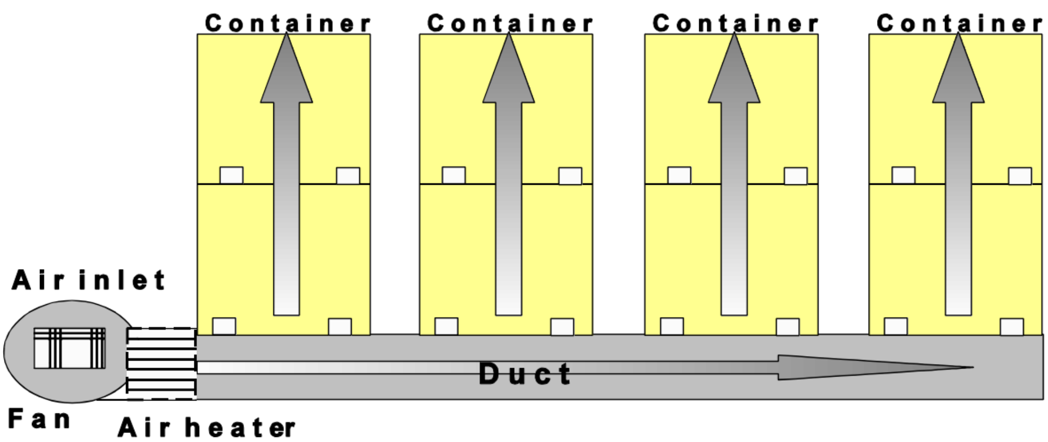

FIGURE 16: Example of a container dryer (Arason, 2003)

Container/ Secondary dryer
This is normally used as the secondary dryer for fish in Iceland. The air is blown through the container to allow drying of the inner parts of the fish after surface drying.

Components of the dryer
A tunnel dryer selected for fish drying consists of the following:

Heat exchanger
This is the equipment that enables the transfer of heat to the air passing through the dryer. Since the heat is supplied from the geothermal resource, the heat exchanger will protect the dryer and other equipment from corrosion, scaling or impurities depending on the material that the drier is being built with to maintain the hygienic conditions (Popovska -Vasilevska, 2003). Plate heat exchangers are suitable for the two dryers selected.

Fan/ Blower
The fan or blower is an important component in the dryer as it allows the blowing of the heated air evenly over or through the product.

Drying chamber
The drying chamber is where our product is being placed. The material used for the drying chamber should be free from rust to protect the product from contamination.

Moisture meter
This will allow monitoring of the moisture while drying so that the product does not become too dry or is incompletely dried what would results in the destruction of the product.

4.2.3 Conveyor band dryer

This is the type of dryer where the air is being forced through the bed of the product by using a blower. The product is placed on a conveyor and then rolled over the conveyor until the drying process is complete. It is suitable for products that do not stick together and is used for fish drying in Iceland as shown in Figure 17 (Arason, 2019).

4.2.4 Spray dryer

This is a dryer where a liquid is injected into hot gas where it is vaporised leaving behind the dried solid particle. This type of dryer is used to

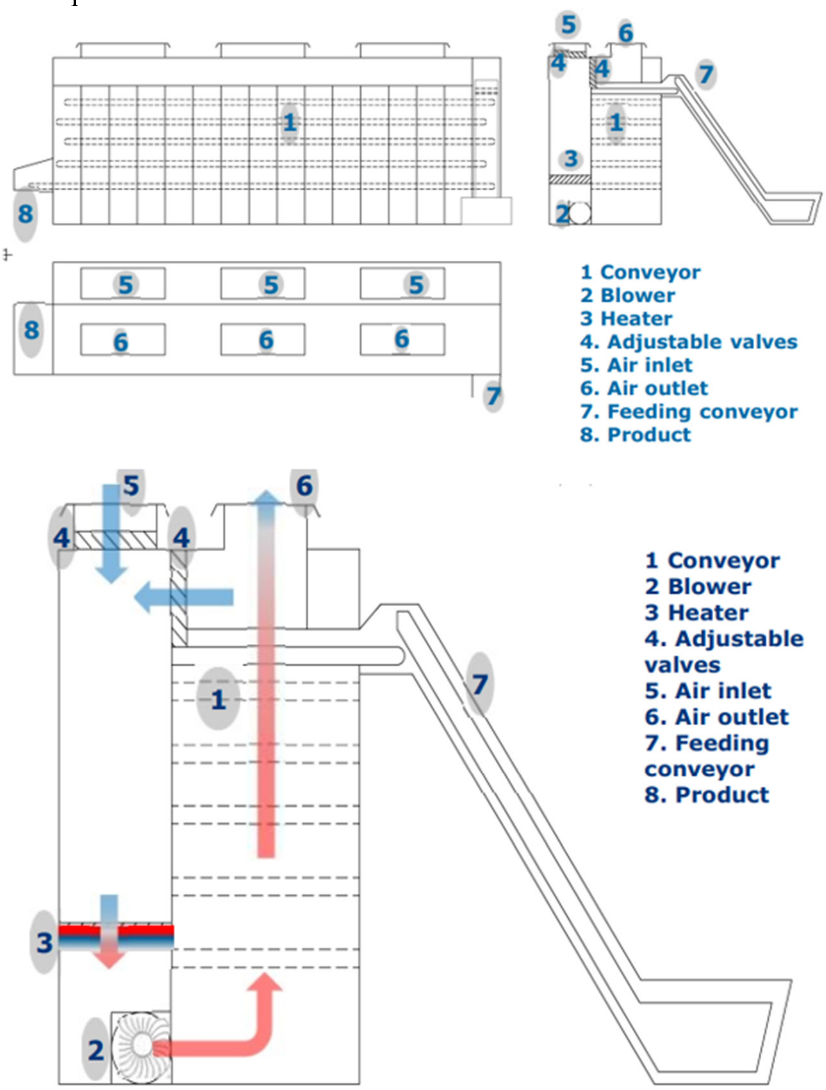

FIGURE 17: Example of a conveyor band dryer (Arason, 2019)

produce milk powder, coffee etc. (Geankoplis, 1993) and is shown in Figure 18.

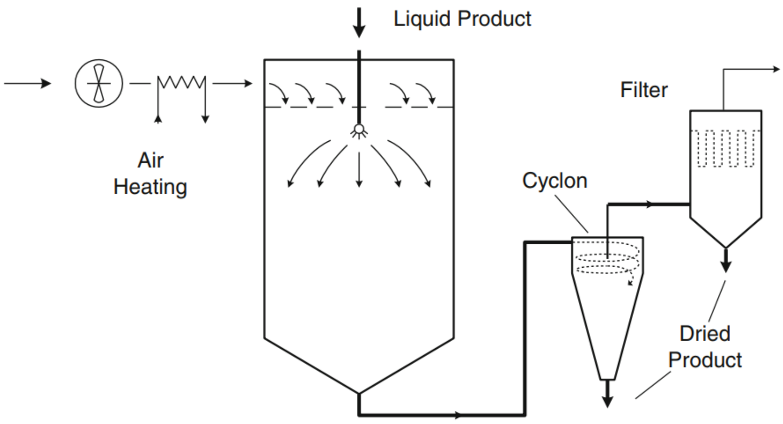

FIGURE 18: Spray dryer (Saravacos and Kostaropoulos, 2016)

4.2.5 Drum dryers

This type of dryer uses drums or rollers to remove the water from a puree, liquid food or pulp and the product output is in form of thin pieces which are continuously removed from the drums. The drum can be single or double and the dryer can be operated under vacuum for very heat sensitive products, but normally it is operated under atmospheric pressure. Figure 19 shows an example of a drum dryer (Saravacos et al., 2016).

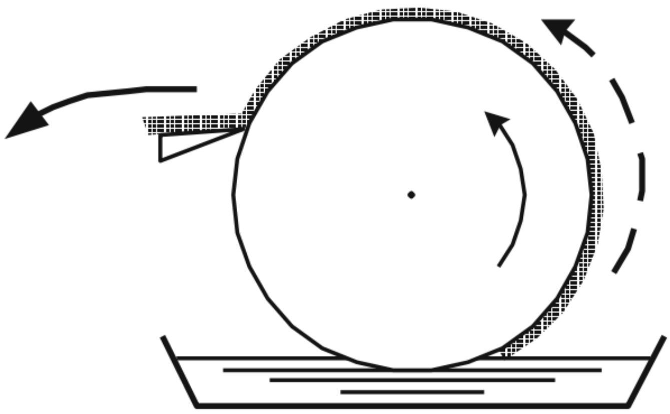

FIGURE 19: Single drum dryer (Saravacos and Kostaropoulos, 2016)

4.2.6 Fluidized bed dryer

In this dryer air is blown through the material through perforations in the bottom of the drying chamber. This dryer can be used for the very fine particles at the size of 10 μm to 20 mm such as grains. It is normally used for products that are free flowing granule such as carbohydrates, products for beverage, ceramics, pesticides, powder pharmaceuticals etc. as shown in Figure 20 (Geankoplis, 1993; Mujumdar, 2006).

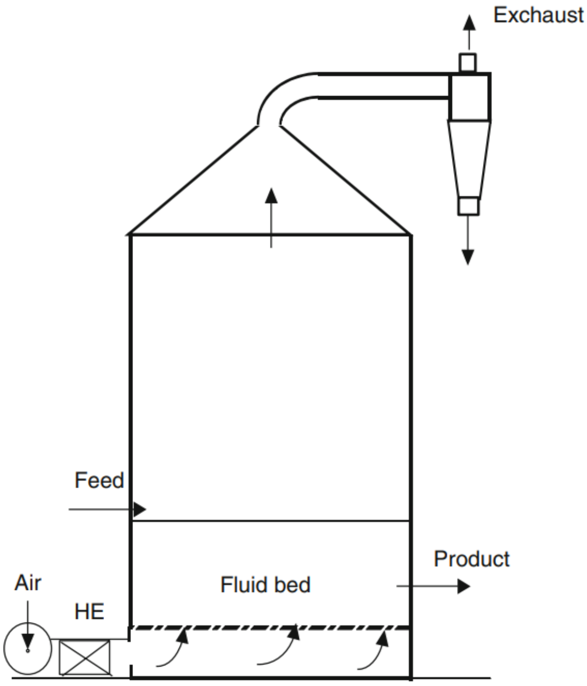

FIGURE 20: Fluidized bed dryer (Saravacos and Kostaropoulos, 2016)

4.3 Drying processes

The drying process can be split into two drying periods, a constant drying rate period and the falling drying rate period as seen in Figure 21. At the constant drying rate period, the solid product is very wet and has water at its surface which is removed by evaporation. The falling drying rate period starts when the product is at the critical moisture content and the surface water has been removed completely. When the product is dry it is left to vaporise slowly to attain zero equilibrium moisture content (Arason, 2003). For the first part of drying, the air temperature can be set high but may not heat up the food. This process depends on the humidity, temperature, pressure, air flow and the exposed area to the environment. After the surface moisture of the food is removed, the inner moisture in the food is lost by diffusion and capillary action to the product´s surface (Ingvarsson, 2014).

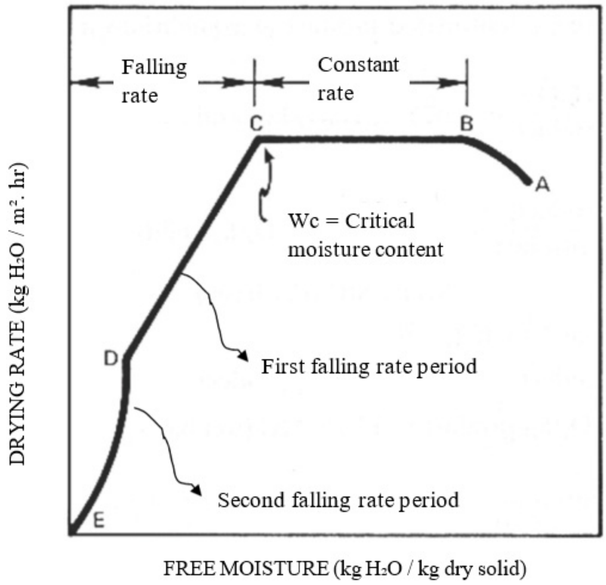

FIGURE 21: Constant and falling rate period of drying (Ankara University, 2019)

5. DESIGN CONSIDERATIONS

According to Geankoplis (1993), it is importantly to know the size of the drier, the humidity, temperature and time required for drying the given amount of the product. Also, one has to understand the process that has to be undertaken before drying. Two products, fish and maize, are discussed in this paper and while maize requires only minor preparations the preparations of fish before drying are more extensive. Below in Figure 22 and 23 the sequence of preparations for both products is described.

Standard moisture content of grain ranges from 10 to 15%. Depending on the type of grain and the time that it is being stored the moisture content has to be lower than 1-2% (Reykdal, 2018).

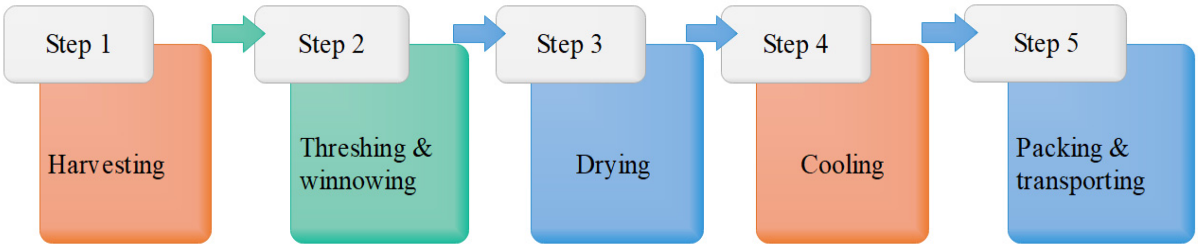

FIGURE 22: Processing chain of maize drying

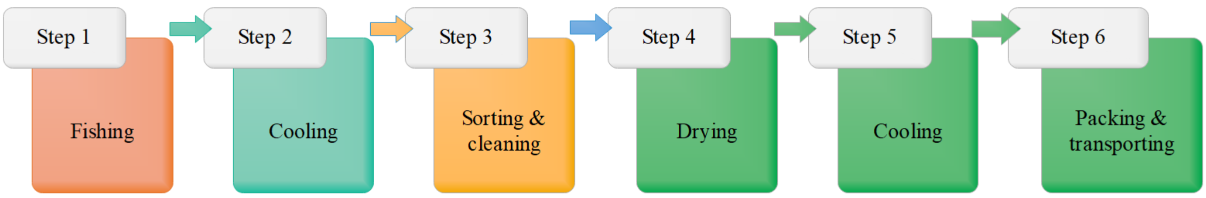

FIGURE 23: Processing chain of fish drying

- Maize - harvesting, threshing, winnowing, drying, cooling, packing and transporting
- Fish- fished, cooled, sorted and cleaned, dried, stored to cool and packed for storage

Standard moisture content of fish ranges from 10 to 12% depending on the type of fish (Arason, 2019).

5.1 Calculations

Samples of the design and calculation of fish and corn driers are shown here, but most of the work is presented in Appendices I and II. There, the main quotations used in designing and shaping these dryers are given, as well as detailed explanations and calculations. Here, only the basic formulas used for the calculations are given:

Area of each tray: $$A = l * w \quad (1)$$

Volume of each tray: $$V = l * w * h \quad (2)$$

where A = Area (m^2);
V = Volume (m^3);
l = Length (m);
w = Width (m);
h = Height (m).

The *Law of Conservation of Mass Balance* under steady-state condition gives:

$$M_f = M_v + M_p \quad (3)$$

For material balance on the moisture:

$$M_f * X_f = M_v * X_v + M_p * X_p \quad (4)$$

where M_f = Mass of the food entering the dryer (kg);
M_v = Mass of the vapour leaving the dryer (kg);
M_p = Mass of the product dried (kg);
X_f = Moisture content of food (kg/kg dry air);
X_v = Moisture content of food vapour leaving the dryer (kg/kg dry air); and
X_p = Moisture content of dried product (kg/kg dry air).

The weight of water evaporated per hour *m* is:

$$m = \frac{M_v}{t} \quad (5)$$

$$\rho = \frac{M_g}{V_a} \quad (6)$$

where ρ = Density of air = 1.2 kg/m^3;
V_a = Volume (air m^3);
M_a = Mass (air kg).

The product yield is:

$$Yield = \frac{M_p}{M_f} * 100\% \quad (7)$$

where M_p and M_f is defined above (Equation 4).

The amount of air flow G needed is:

$$G = \frac{\triangle M}{\triangle x} \quad (8)$$

where $\triangle M$ = Difference in raw material and product = M_f - M_a,or mass of the food entering the dryer (kJ/kg air);
$\triangle x$ = Change in moisture content of air = $x_3 - x_4$ (kg water / kg air);

and the amount of hot air blown over the product G´ is:

$$G' = \frac{\frac{M_v}{h}}{\triangle x} \tag{9}$$

where G' = Mass velocity (kg air / h m^2).

For the heating requirement;

$$Q = \triangle i * G \tag{10}$$

where Q = Energy requirement (kJ/h);
Δi = Difference in enthalpy ($i_3 - i_2$).

The amount of hot water needed can be calculated as follows:

$$Q = M_{hw} * C_p * \Delta T \tag{11}$$

where M_{hw} = Hot water (kg water/h);
C_p = Specific heat capacity (J/(K*kg)); and
ΔT = Difference in water ($T_{in} - T_{out}$).

The amount of hot air used is calculated as follows:

$$\frac{\text{Tons of hot water, } M_h}{\text{Tons of product, } M_p} = \frac{M_{hw}}{M_p} \tag{12}$$

If the heat is transferred by convection, we neglect heat transfers by radiation and conduction (Geankoplis, 1993):

$$q = h * A * \triangle T \tag{13}$$

where q = Convective heat transfers (J/s);
h = Heat transfer coefficient (W/m^2 °C);
A = Drying area (m^2); and
$\triangle T$ = Temperature change between the surface and hot air entering the drier (°C).

If the flow of air was parallel to the surface of the drier, then Equation 13 would be applicable but due to turbulent flow caused by air temperatures of 45 to 150°C and a mass with velocity G of 2450 to 29300 kg/h m^2 or at the velocity of 0.61 - 7.6 m/s (Geankoplis, 1993):

$$h = 0.0204G^{0.8} \tag{14}$$

But since the flow is perpendicular flow to the surface of the drier for G of 3900 - 19500 kg/(h*m^2) or with the velocity of 0.9 - 4.6 m/s, then:

$$h = 1.17G^{0.37} \tag{15}$$

For a constant drying rate, the drying time is calculated as follows:

$$t = \frac{Ls * \lambda_w * \triangle X}{A * h * \triangle T} \tag{16}$$

where λ_w = Latent heat (kJ/kg);
L_s = Amount of dried solid (kg); and
$\triangle X$ = Difference in water content (kg water/kg air).

Since we assume that conduction and radiation heat transfer does not occur, the rate of drying at constant period R_c is proportional to h and $G^{0.37}$ referring to Equation 15 for perpendicular flow of air to the surface of the drier. The heat is transferred by convection, hence the rate of drying R_c is independent of thickness of product.

$$R_c = \frac{h * \triangle T}{\lambda w} \tag{17}$$

With reference to Equation 15:

$$R_c = \frac{1.17G^{0.37} * \triangle T}{\lambda w} \tag{18}$$

where $\triangle T$ = Change in temperature (°C); and
R_c = Rate of constant drying (h).

The humidity only depends on the partial pressure of water vapour in the air and on the total pressure which is 101.325 kPa. Using the molecular weight of water 18.02 and of air 28.97, the humidity is calculated as (Geankoplis, 1993):

$$H = \frac{18.02 \ P_a}{28.97 \ (P - P_{as})} \tag{19}$$

where H = Humidity (%);
P_a = Partial pressure (kPa);
P = Total pressure (kPa); and
P_{as} = Vapour pressure of pure water (kPa).

Since the percentage humidity is 100 times the actual humidity, the percentage humidity can be calculated as,

$$H_p = 100 \frac{H}{H_s} \tag{20}$$

where H_p = Percentage humidity of the air (%).
H = Actual humidity of the air (%).
H_s = Humidity of air if it where saturated (%).

The relative humidity can be calculated using the partial pressures as follows:

$$H_r = 100 \frac{P_a}{P_{as}} \tag{21}$$

where H_r = Relative humidity (%).
P_a = Partial pressure (kPa).
P_{as} = Vapour pressure of pure water (kPa).

5.2 Graphical drying representation

This paper discusses maize and fish as examples for food products. Table 1 shows the comparison between fish drying and maize drying. It takes longer to dry fish than maize because fish has different physical characteristics than maize, that is higher water activity. Fish requires two processes to completely dry, primary drying that allow the surface of the fish to dry and secondary drying that allows the inside of the fish to dry. Maize normally dries up in the field before harvesting due to the tropical weather conditions, so it has already undergone the primary drying. Thereafter, it only takes a few hours to complete the secondary drying process. Maize is dried from an initial moisture content of 35% down to 10% in 8 hours while fish is dried from a moisture content of 80 to 12% in 15 hours in primary drying and 30 hours secondary drying (Figure 24).

TABLE 1: Reduction of weight and moisture in maize and fish during drying

Drying time (h)	**Maize**		**Fish**	
	MC (%)	**W (%)**	**MC (%)**	**W (%)**
1	35	1000	80	1000
2	30	929	75	800
3	25	867	70	667
4	20	813	67	606
5	17	783	64	556
6	14	756	61	513
7	12	739	60	500
8	10	722	58	476
9			57	465
10			55	444
11			53	426
12			51	408
13			50	400
14			48	385
15			46	370
16			44	357
17			43	351
18			42	345
19			41	339
20			40	333
21			39	328
22			38	323
23			37	317
24			36	313
25			35	308
26			34	303
27			33	299
28			32	294
29			31	290
30			30	286
31			28	278
32			26	270
33			24	263
34			23	260
35			22	256
36			21	253
37			20	250
38			19	247
39			18	244
40			17	241
41			16	238
42			15	235
43			14	233
44			13	230
45			12	227

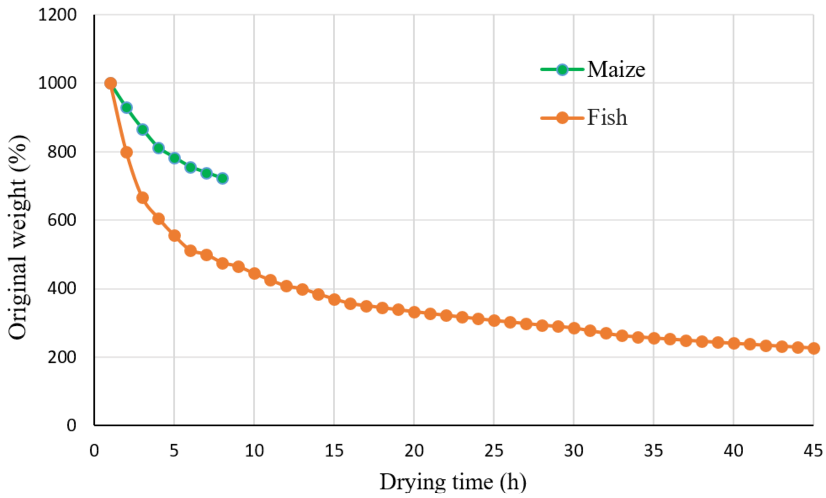

FIGURE 24: Comparing fish and maize drying

5.3 Storage

Proper storage (the equipment, material used and condition of the surrounding) is a major contributor to the elongation of the product's shelf life. Correct drying can be wasted due to improper packaging or storage. Maize can be stored in bins or silos to eliminate insects or moulds reaching the product.

5.4 Cost evaluation

Drying cost depends on the investment, operations and delivery of product. Tunnel and container dryers can dry a 1,000 kg batch for approximately USD 25,000 while the fluidized bed dryer dries 2,000 kg/h for approximately USD 55,000. This might change since the exact location of the drilling is not decided yet. Other food products than discussed here such as cocoa, tea, bananas, avocado etc. might available closer to the resource. Hence, the exact cost should be calculated after the resource has been confirmed.

6. DISCUSSION

The dryer design selected for fish drying is the tunnel dryer (Figure 1 in Appendix I) where the inlet air flows through the inlet door and passes through the heat exchanger where it is warmed and evenly distributed by a fan. Secondary drying is performed by a container dryer. The calculations were made for primary and secondary drying (Figures 2 and 3 Appendix I). For maize we recommend the fluidized bed dryer. The maize is fed into the dryer through a receiver bin at the top and then moves at equal velocity to the drying chamber where the hot air is flowing perpendicular while the maize moves downward. Then cool air is blown through, as shown for the fluidized bed dryer in Figure 1 in Appendix II. The calculations are shown in the process diagram in Figure 2 in Appendix II. They were made using the assumptions given in Tables 1 and 2 in Appendices I and II for fish and maize drying, respectively.

The results from the calculations are tabulated in Table 2 below. It was assumed that the 80°C hot water (geothermal water) enters the heat exchanger where the secondary fluid (air) is heated to a temperature of 28°C for the tunnel dryer (fish drying) and to 40°C to the fludized bed dryer (maize drying). A relative humidity of 45% is assumed after the sensors allow the valve to open and the air enters the dryer and blows over the fish or maize. Maize has a yield of 72.2% while fish has a yield of only 22.7% due to their differences in structure, shape and water activity. Also, fish has a higher moisture content, or 80% compared to 35% in maize. Therefore, heat requirement and amount of hot water needed to dry fish is higher than for maize.

TABLE 2: Results of the calculations for drying fish and maize

	Fish	Maize
Weight of raw product	1000 kg	1000 kg
Initial water content	80%	35%
Final water content	12%	10%
Water activity	0.55	0.5
Duration	45 hours	8 hours
Dried weight	227.3 kg	927.8 kg
Geothermal hot water	63 tons/ ton product	6 tons/ton product
Heat requirement	154,980 kJ/h	106,769.2 kJ/h
Rate of water evaporated	44.3 kg air/h	34.7 kg air/h
Rate of hot air blown	22,095 kg air/h	26,692.3 kg air/h
Yield	22.70%	72.20%

7. CONCLUSION

This paper has highlighted the possibilities of using geothermal resources available in the country for drying food products like fish and maize. The two food products have different characteristics and were purposely selected to show that the geothermal dryers can dry any type of food products available in Tanzania after thorough study of the required temperature, humidity and air flow. It is also important to consider the storing facilities as they have impact on the dried product. The implementation of the results presented in this paper will have a huge impact on the food and industrial processing sector and the rural communities, especially women who are the main producers of the raw materials close to the geothermal resource.

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APPENDIX I: Detailed explanations and calculations for design of dryers for fish

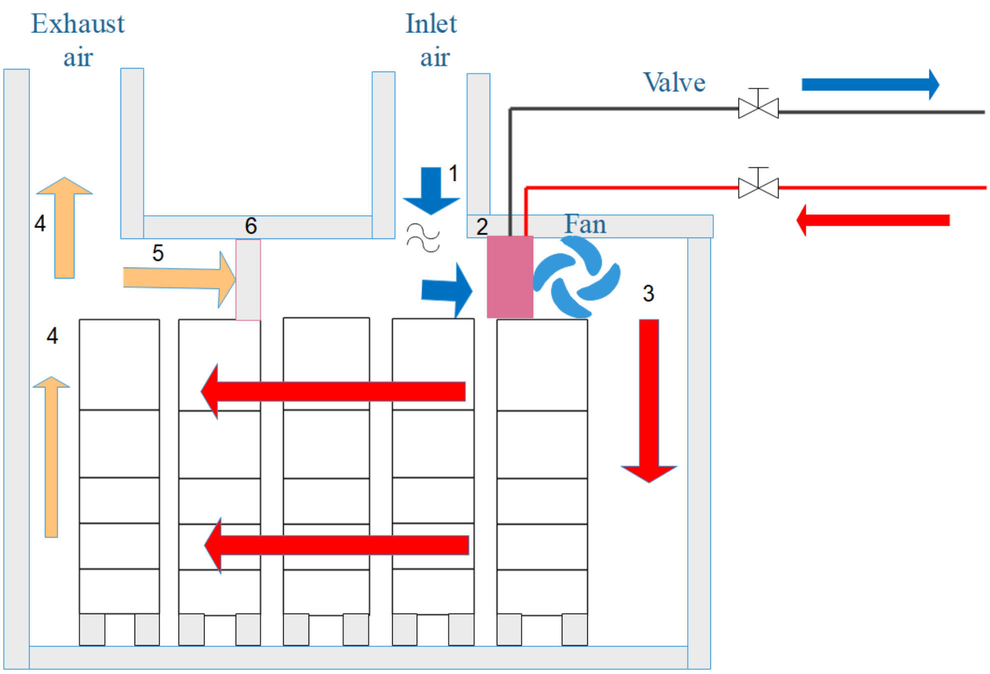

FIGURE 1: Design of a tunnel drier for fish drying

TABLE 1: Input values for drying fish

Description	Variables
Amount of the wet fish	1000 kg
Moisture content of fish; inlet (X_i)	80%
Temperature of air entering the drier	26 °C
Temperature of the heated air	28 °C
Temperature of air leaving the drier	23 °C
Final moisture content at primary drying (X_{fp})	55%
Final moisture content at secondary drying (X_{fs})	12%
Relative humidity (RH)	45 %
Humidity of the surrounding	80 %
Temperature of water entering the heat exchanger (T_{ih})	80°C
Temperature of water leaving the heat exchanger (T_{oh})	35°C
Time for primary drying (t_p)	15 hours
Time for primary drying (t_s)	30 hours
Specific heat capacity of water (C_p)	4.2 kJ/kg °C
Density of air (ρ)	1.2 kg/m³

For the design of each tray:
Number of cabinets: 5
Number of trays per cabinet: 5
Number of trays in the drier = 5 * 5 = 25 trays

Dimension of the tray: Length (l) = 0.5 m
Width (w) = 0.25 m
Height (h) = 0.25 m
Spacing of each cabinet = 0.25 m

Referring to Equation 1:

Area of each tray: $A = l * w$

$A = 0.5 \text{ m} * 0.25 \text{ m} = 0.125 \text{ m}^2$

Volume of each tray: $V = l * w * h$

$V = 0.5 \text{ m} * 0.25 \text{ m} * 0.25 \text{ m} = 0.03125 \text{ m}^3$

Primary drying:
Referring to Equation 4 and Table 1, using $X_f = 0.2$, $X_v = 0$, $X_p = 0.45$:

$$1000 * 0.2 = M_v * 0 + M_p * 0.45$$

$\mathbf{M_{p1} = 444.4\ kg}$ (primary drying)

$$\mathbf{M_v = M_f - M_p = 1000 - 444.4 = 555.6\ kg}$$

$$\mathbf{M_{v1} = 555.6\ kg} \text{ (primary drying)}$$

The weight of water evaporated per hour:

$\mathbf{M_{v1}}$ for primary drying is: $\rho = \frac{m}{v}$

$\boldsymbol{m_1 = 555.6/15 = 37.04}$ **kg air/h**

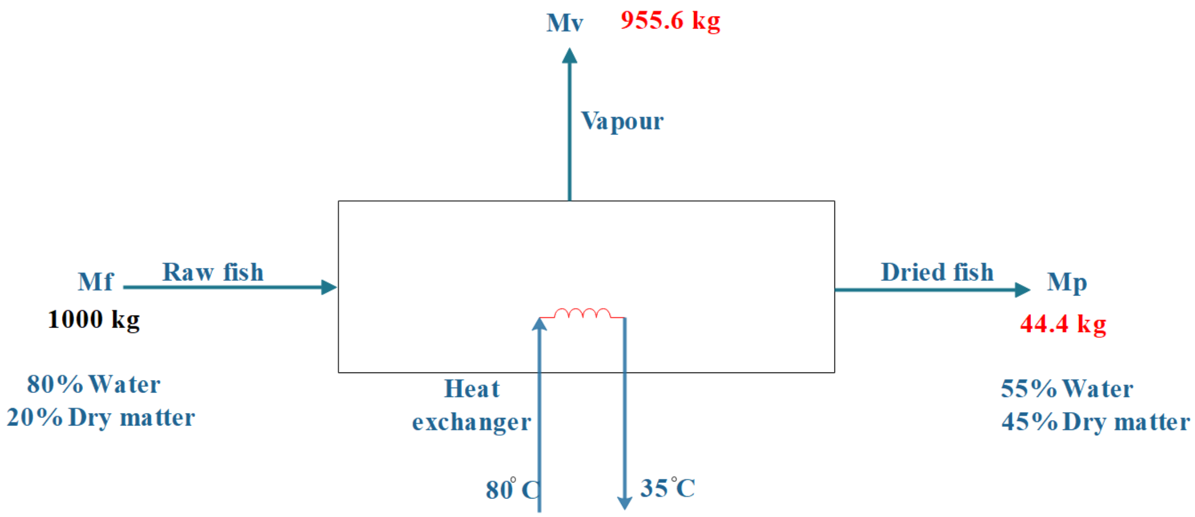

FIGURE 2: Process flow diagram for primary drying of fish

Referring to Equation 6 and ρ = density of air = 1.2 kg/m³:

$$\rho = \frac{m}{v}$$

$$v = \frac{m}{\rho}$$

v = 37.04 kg/h / 1.2 kg/m^3 = 30.9 m^3/h

Air flow rate needed is 30.9 m³/h for primary dying.

Secondary drying:

Mass balance of moisture:

$$M_f * X_f = M_v * X_v + M_p * X_p$$

where $X_f = 0.45$, $X_v=0$, $X_p=0.88$

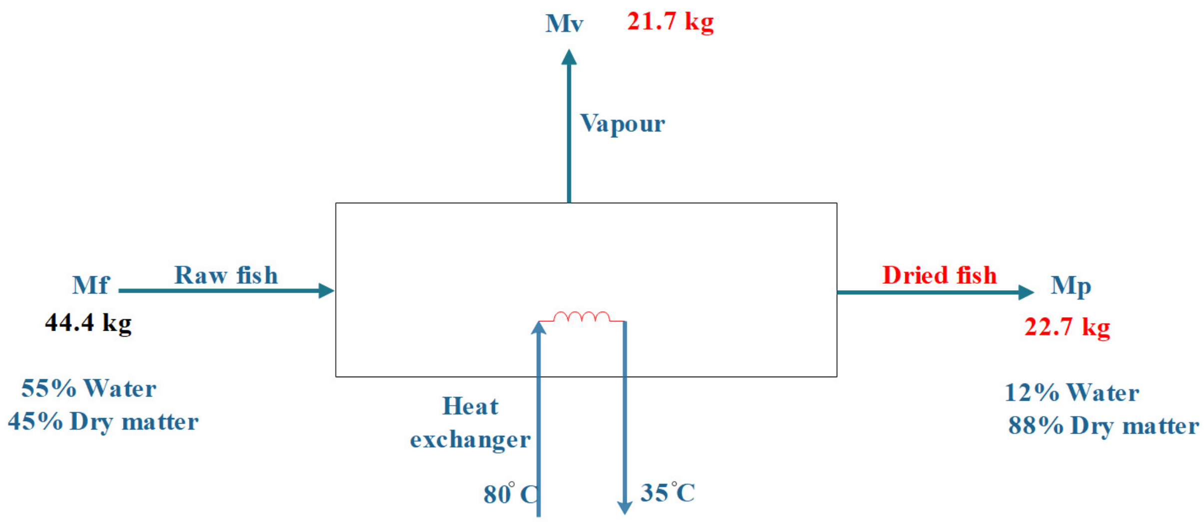

FIGURE 3: Process flow diagram for secondary drying of fish

$$444.4 * 0.45 = \mathrm{M_v} * 0 + \mathrm{M_p} * 0.88$$

$\mathbf{M_{p2} = 227.3\ kg}$ (secondary drying)

$\mathrm{M_v = M_f - M_p = 444.4 - 227.3 = 217.1\ kg}$

$\mathbf{M_{v2} = 217.1\ kg}$ (secondary drying)

The weight of the product after primary and secondary drying is $\mathbf{M_{p2}}$ **= 227.3 kg**

The weight of water evaporated during primary and secondary drying is $\mathbf{M_{v2}}$ **= 217.1 kg**

The weight of water evaporated per hour $\mathbf{M_{v2}}$ for secondary drying is:

$$m_2 = \frac{\mathbf{M_{v2}}}{\mathrm{t}}$$

m_2 = 217.1 / 30 = 7.24 kg air/h

Referring to Equation 6:

v = 7.24 kg/h / 1.2 kg m^3 = **6 m^3 / h**

The air flow rate needed is 6 m^3/h for secondary dying.

The total amount of water evaporated in the two-step drying (primary and secondary drying) is:

$$\mathrm{M_v} = m_1 + m_2$$

M_v = 37.04 + 7.24 = 44.3 kg air / h

The amount produced, referring to Equation 6:

$$\mathrm{Yield} = \frac{\mathrm{M_p}}{\mathrm{M_f}} * 100\%$$

Yield = 227.3 / 1000 * 100 % = 22.7%

The calculations are correctly inserted in the Mollier diagram with the calculations matching the conditions of the air. Taking the reading from the Mollier chart whereat the drier, x_2=x_3, i_3=i_4:

TABLE 2: Psychometric data values from the Mollier diagram

Sn	**T (°C)**	**HR (%)**	**x (kg water / kg air)**	**i (kJ / kg air)**
1	**22**	**70**	0.0113	50
2	26	66	0.014	63
3	**35**	**45**	0.014	70
4	**30**	80	0.016	70

Since,

$$\triangle \mathbf{i} = \mathbf{i_3} - \mathbf{i_2}, \quad \triangle \mathbf{x} = \mathbf{x_4} - \mathbf{x_3}$$

$\triangle$i = 65-48 = 7 kJ/kg air

$\triangle$x = 0.0126 - 0.0106 = 0.002 g water / kg air

The amount of air flow needed, referring to Equation 7, is:

$$\frac{Q}{\text{kg vapour}} = \frac{\triangle i}{\triangle x}$$

Q / kg vapour = (7 kJ/kg air) / ((2 g water/kg air)/1000)

Q = 3500 kJ/kg vapour

Amount of hot air blown over the product G for both primary and secondary drying

with G'_p = Amount of hot air blown for primary drying
G'_s= Amount of hot air blown for secondary drying

is estimated as the following, referring to Equation 8:

Primary drying:

$$G'_p = \frac{\frac{\mathbf{M_v}}{h}}{\triangle X}$$

G'_p = 37.04 /0.002 = 18,520 kg air/ h

Secondary drying:

$$G'_s = \frac{\frac{\mathbf{M_v}}{h}}{\triangle X}$$

G'_s = 7.24 / 0.002 = 3,620 kg air / h

Heating requirement

Primary drying:

$$\mathbf{Q} = \triangle \mathbf{i} * \mathbf{G'}$$

Q = 7 * 18,520 = 129,640 kJ/h

Secondary drying:

Q = 7*3620 = 25,340 kJ/h

Total heat required for primary and secondary drying is 154,980 kJ/h

Referring to Table 2, the **amount of hot water needed for a ton of product is calculated as follows:**

$$\mathbf{Q = M_{hw} * C_p * \triangle T}$$

Primary drying:

$$\mathbf{M_{hw} = \frac{Q}{C_p * \triangle T}}$$

M_{hw} = 129,640 kJ/h / (4.2 kJ/kg°C * (80-35) °C = 686 kg/h

With drying time as: t = 15 hours (primary drying) and t = 30 hours (secondary drying), we get:

M_{hw} = 686 kg/h * 15 h = 10,290 kg = 10.3 tons of water

$$\mathbf{M_{hw} = 10{,}290\ kg = 10.3\ tons\ of\ water}$$

Secondary drying:

M_{hw} = 25,340 kJ/h / (4.2 kJ/kg°C * (80-35) °C) = 134.1 kg/h

M_{hw} = 134.1 kg/h * 30 h = 4,023 kg

$$\mathbf{M_{hw} = 4{,}023\ kg = 4\ tons\ of\ water}$$

Referring to the calculations above the need for hot water for 1 ton of product is the following:

M_p = 227.3 kg = 0.227 tons of product

$$\mathbf{\frac{Tons\ of\ hot\ water}{Tons\ of\ product} = \frac{M_{hw}}{M_p}}$$

Hot water (tons) / product (tons) = (10.3 + 4) / 0.227 or

63 tons of hot water are required to dry 1 ton of product.

APPENDIX II: Detailed explanations and calculations for design of dryers for maize

TABLE 1: Input values for drying maize

Description	Variables
Amount of maize	1000 kg
Moisture content of maize; inlet (X_f)	35%
Moisture content of maize; outlet (X_o)	10%
Temperature of air entering the drier	26 °C
Temperature of the heated air	43 °C
Temperature of air leaving the drier	40 °C
Final moisture content drying (X_f)	10%
Relative humidity (RH)	45 %
Humidity of the surrounding	80 %
Temperature of water entering the heat exchanger ($\mathbf{T_{ih}}$)	80°C
Temperature of water leaving the heat exchanger ($\mathbf{T_{oh}}$)	35°C
Time for primary drying ($\mathbf{t_p}$)	8 hours
Specific heat capacity of water ($\mathbf{C_p}$)	4.2 kJ/kg °C
Density of air (ρ)	1.2 kg/m³

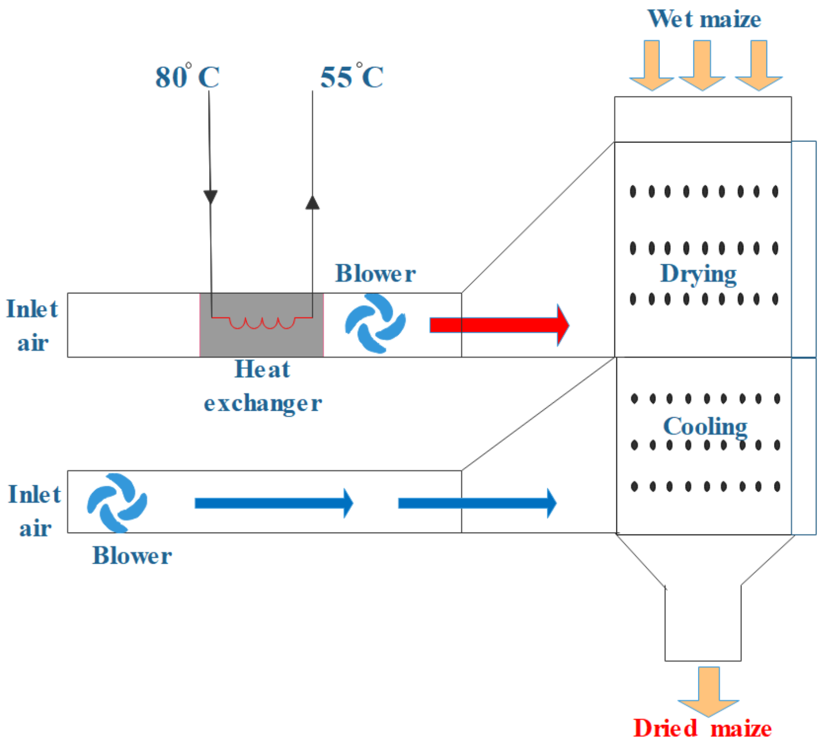

FIGURE 1: Design of fluidized bed dryer for drying maize

With reference to the mass balance Equation (Equation 4):

$$M_f * X_f = M_v * X_v + M_p * X_p \quad \text{where } X_f = 0.65,\ X_v = 0,\ X_p = 0.9$$

$1000 * 0.65 = Mv * 0 + M_p * 0.9$

$\mathbf{M_p = 722.2\ kg}$

$$M_v = M_f - M_p = 1000 - 722.2$$

$\mathbf{M_v = 277.8\ kg}$

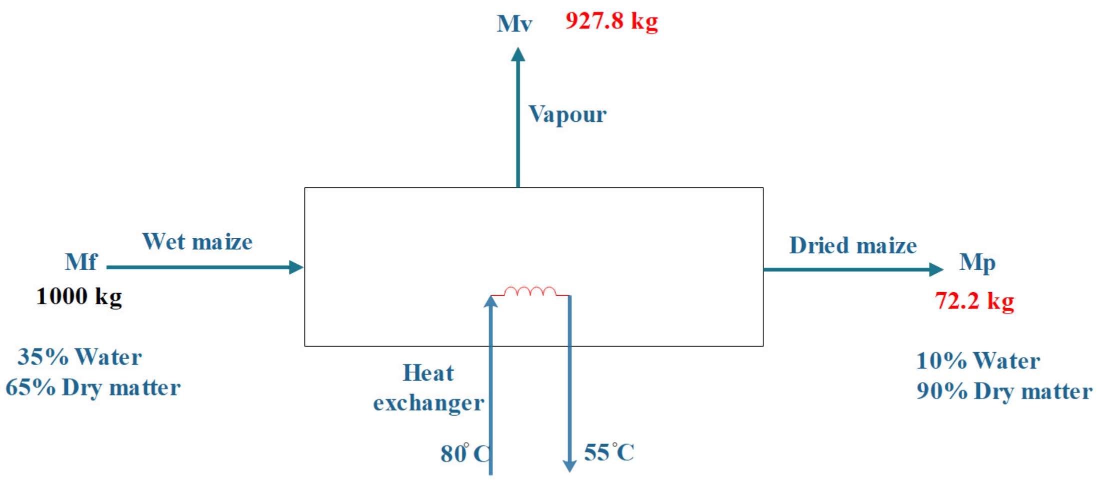

FIGURE 2: Process flow diagram for one step drying of maize

The weight of the product after primary and secondary drying is $\mathbf{M_p = 722.2}$ **kg.**

The weight of water evaporated during primary and secondary drying is $\mathbf{M_v = 277.8}$ **kg.**

The weight of water evaporated per hour **m** is:

$$m = \frac{M_v}{t}$$

m = 277.8 /8 kg = 34.7 kg air / h

From ρ = density of air = 1.2 kg/m³ we get:

$$\rho = \frac{m}{v}$$

$$v = \frac{m}{\rho}$$

v = 34.7 kg/h / 1.2 kg/m^3 = 29 m^3/h

Air flow rate needed is 29 m³/h.

The amount produced is:

$$\text{Yield} = \frac{M_p}{M_f} * 100\%$$

Yield = 722.2/1000 * 100 % = 72.2%

TABLE 2: Psychometric data values from the Mollier diagram

Sn	T (°C)	HR (%)	X (g water /kg air)	i (kJ/kg air)
1	**26**	**80**	0.017	69
2	38	60	0.0255	104
3	**43**	**45**	0.0255	108
4	**40**	56	0.0268	108

$$\triangle \boldsymbol{i} = \boldsymbol{i}\mathbf{3} - \boldsymbol{i}\mathbf{2}, \quad \triangle \mathbf{x} = \mathbf{x4} - \mathbf{x3}$$

△ *i* = 108 – 104 = 4.0 kJ/kg air

△ x = 0.0268 – 0 0255 = 0.0013 g water / kg air

Equation 7 gives:

Q = (4.0 kJ / kg air) / ((1.3 g water / kg air) * 0.001)

Q = 3,077 kJ/kg vapour

Based on Equation 8, the amount of hot air blown over the product G′ is:

$$G' = \frac{\frac{M_V}{h}}{\triangle X}$$

G′ =34.7 / 0.0013 = 26,692 kg air / h

Referring to Equation 9, the heating requirement is calculated as follows:

$$Q = \triangle i * G'$$

Q = 4 * 26,692 kJ/h = **106,769 kJ/h**

$$M_{hw} = M_{hw} * C_p * \triangle T$$

$$M_{hw} = \frac{Q}{C_p * \triangle T}$$

$\mathbf{M_{hw}}$ = 106,769 kJ/h / ((4.2 kJ/kg°C) * (80-35 °C)) = **565 kg/h**

With a drying time, t = 8 h, the water requirements can be calculated as:

M_{hw} = 565 kg/h * 8 h = 4,520 kg = 4.52 tons of water

$$\mathbf{M_{hw} = 4,520\ kg = 4.52\ tons\ of\ water}$$

Referring to the above calculations, M_p = 722.2 kg = 0.722 tons of product.

$$\mathbf{\frac{Tons\ of\ hot\ water}{Tons\ of\ product} = \frac{4.52}{0.722} = 6.3}$$

6 tons of hot water are required for 1 ton of product.