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UTILIZATION OF BRINE WATER FOR COPRA DRYING IN LAHENDONG GEOTHERMAL FIELD, INDONESIA

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ABSTRACT

The separation process of geothermal fluid, more precisely two-phase geothermal fluid, yields dry steam that is supplied directly to a power plant and brine water that is pumped down to the re-injection wells. Brine water gained from the production separator is still carrying a lot of energy at temperatures up to 99°C, and it is obviously better if the energy can be extracted before pumping it back to the reservoir. Geothermal energy is an environmentally friendly, natural resource and commonly operated side by side with a plantation area. The easiest and simplest way to utilize this energy is by collaborating with this plantation activity. One of many ways to utilize the brine water is using it to dry the agricultural products harvested around the geothermal production area. Coconut is one of many agricultural products harvested around Lahendong geothermal field. Most of these coconuts will be dried to produce copra. Generally, copra is still produced with conventional sun drying methods which mostly depend on the weather conditions and sun availability, By utilizing the energy from brine water, the drying process can be continued indoors throughout the whole year.

1. INTRODUCTION

1.1 Lahendong geothermal field

Lahendong geothermal field is one of many potential geothermal areas in Indonesia which is directly operated by Indonesian National Oil and Gas Company PT Pertamina (Persero). Lahendong geothermal field is located in North Sulawesi Province, about 30 km south of Manado, the North Sulawesi Province capital (Figure 1). Exploration activity was started by Pertamina in 1984. Currently, Lahendong geothermal field has geothermal resources of around 170 MWe (probable) or 80 MWe (proven).

Through the year 2006, 23 wells had been drilled in the Lahendong geothermal field. These are able to supply the existing 20 MWe PLTP Unit I and the scheduled 2x20 MWe PLTP Units II and III with steam for production. Milestones and a general overview of well developments in Lahendong geothermal field since its first exploration activities include the following:

- *Exploration drilling 1984 – 1987.*
  Seven exploration wells drilled at different well pads.
- *Production drilling 1988 – 1998.*
  During this period, nine wells were drilled with five production wells in use, with mass flow up to 217 ton/hour to supply 20 MWe PLTP Unit I (147 tons/hour steam consuming).
- *Production drilling 2003 – 2006.*
  During this period, seven new production wells were drilled in order to supply the planned 2x20 MWe expansion power plants of PLTP Units II and III; production test results are yet to be finished to find out the potential of these seven new wells.
- Total number of wells drilled 23 wells.
- Well depth in the range 1500 – 2500 m.
- Reservoir temperature in the range 250 – 350°C.
- Reservoir type: Two-phase geothermal fluid.

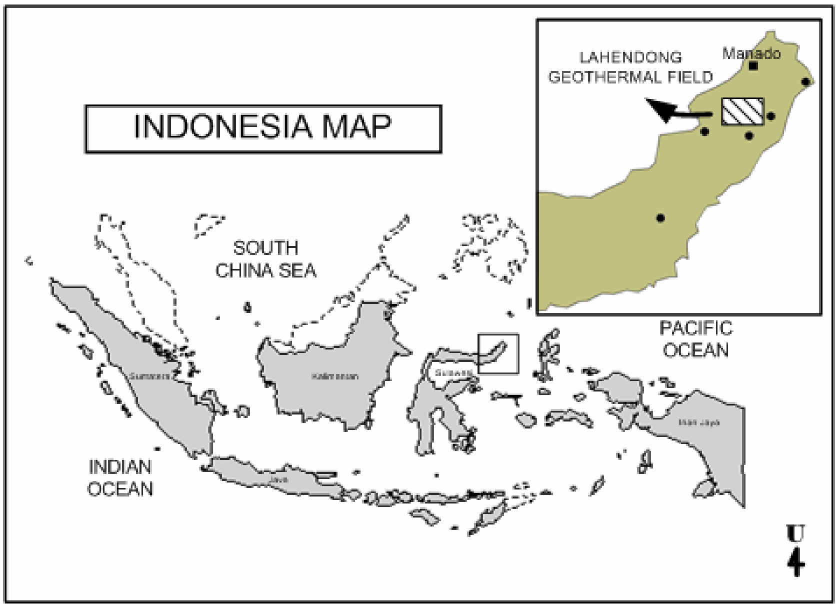

FIGURE 1: Location of the Lahendong geothermal field, Indonesia

The geothermal power plant (PLTP) Lahendong has been operating since August 21st 2001 with a 20 MWe capacity, exploiting dry vapour which is being supplied by five production wells from Lahendong geothermal field. Lahendong geothermal field has a two-phase fluid system; therefore a special process using a separator is needed to dissociate the water contents within the two-phase fluid. Dry steam can be yielded to fulfil minimum power plant standard steam requirements. After passing through the separation process, two-phase fluid inside the separator is separated to water (brine) and dry steam. The dry steam is piped directly to PLTP to drive the steam turbine while the brine water is collected in a cooling pond from where it is pumped to the re-injection well. The brine water produced has a silica saturation index of 1.3, thus it should be collected in a cooling pond to let the silica deposit there instead of inside the re-injection wells. Brine water is pumped back into the re-injection well in an effort to:

- Minimize environmental impact of mixed brine and surface water;
- Maintain the pressure of the geothermal reservoir;
- Assist in the continuity of steam exploitation by giving enough water to the heat source to be re-heated.

Obviously brine water from the separation process still has energy (enthalpy). Water with a temperature range of 20-140°C can be exploited for direct use (Lindal Diagram). For supplying 20 MWe to PLTP Lahendong, 40 tons/hour brine is produced from a steam separation process with temperatures up to 99°C. This brine volume will increase when power plant unit II and III are ready to run. There is still a lot of energy content inside the brine water; we can extract that energy before we inject the brine to the re-injection wells

1.2 Coconut potential resource

Indonesia has the largest coconut plantation with 31.12% of the total coconut plantation area in the world followed by the Philippines (25.8%), India (16.0%), Sri Lanka (3.7%) and Thailand (3.1%). Although Indonesia is the largest coconut plantation country, it places second for total coconut production after the Philippines and is below India and Sri Lanka for product diversification. (APCC, 2004 in Indonesian Agency for Agricultural Research and Development, 2005)

It is an ordinary situation that geothermal natural resources are located in the highlands, in an ex-cauldron area or within a dormant/inactive volcano. We can find plantation and agricultural activities in the highlands which have fertile lands caused by past volcanic activity. It can be taken as an analogy that where geothermal resources exist, they will always be side by side with plantation or agricultural activities. PT Pertamina AG Lahendong geothermal field is operated next to a plantation and agriculture environment growing corn, cloves, rice plants, coconut and many others.

North Sulawesi province, where Lahendong geothermal field lies, is one of many coconut plantation areas in Indonesia. North Sulawesi coconut plantation area covers 352,583 ha (68.46%) of the total plantation area in this province, with 28,528 tons of coconut meat production annually in year 2004 (North Sulawesi Province Statistic Office, 2006)

This potential coconut resource can be developed further to gain more advantage. Nowadays people produce copra from it with conventional sun drying and burned hot air method. These methods, especially the sun drying method, have many limitations because it is dependent on the sun and weather conditions. This is especially true in rainy seasons, so it is not possible to produce over the whole year.

2. DRYING THEORY

2.1 Introduction

Drying is perhaps the oldest, most common and most diverse of chemical engineering unit operations. Over four hundred types of dryers have been reported in the literature while over one hundred distinct types are commonly available. Energy consumption in drying ranges from a low value of under five percent for the chemical process industries to 35% for papermaking operations. Nowadays the drying techniques can take little space, can be done year round, and are simple, safe alternatives to canning and freezing foods. Drying occurs by inducing vaporization of the liquid by supplying simultaneous heat to the wet feedstock. Heat must be transferred to equal the heat of evaporation. If the heat supply is less than the amount of evaporation, the temperature of the material will drop causing an unstable drying process. If the heat supply is more than the amount of evaporation, the temperature of the material rises which can cause many problems such as colour changes, hardening, and other chemical reactions. Heat may be supplied by convection (direct dryers), by conduction (contact or indirect dryers), radiation or volumetrically by placing the wet material in a microwave or radio frequency electromagnetic field. Over 85% of industrial dryers are of the convective type with hot air or direct combustion gases as the drying medium. Over 99% of the applications involve the removal of water.

Each product and material has its own drying curve that describes its drying behaviour. Drying occurs in three different phase (Figure 2):

- *Initial period.* This is the initial condition where the product is first loaded into the drier. The temperature of the product will go up, close to the drying temperature; the product drying rate will increase.

- *Constant period*. During this period the drying rate becomes flatter while the water evaporation equals the water particle movement from inside the product. The drying rate is high without any significant product temperature changes.
- *Falling rate period.* During this period the water particle movement from the centre of the product to the surface becomes very slow. This condition makes the drying rate decrease until there is no water to be evaporated and the temperature of the product rises.

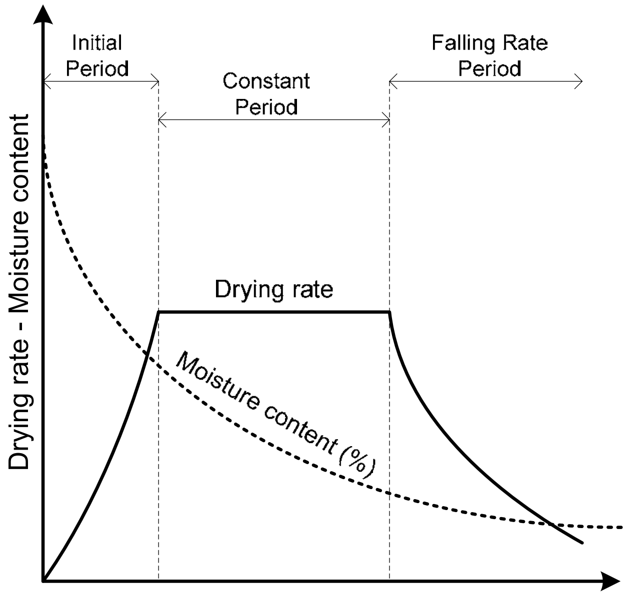

FIGURE 2: Typical drying rate behaviour curve

The main purposes of the drying process are to:

- Remove moisture from food so bacteria, yeasts and moulds cannot grow and spoil food;
- Slow down the action of enzymes without making them inactive;
- Preserve the product by preventing/inhibiting micro-organisms;
- Reduce product volume and weight;
- Reduce water content for transport, and handling;
- Storage for the marketing process;
- Provide a step up to the next type of processing;
- Exploit the fluid from the product.

The product or material drying rate depends on (Dryden, 1975):

- *External factors:*
  - The drying air temperature;
  - Humidity;
  - Velocity and turbulence:
  - Material surface area and thickness.

- *Internal factors:*
  - The nature of the material affects the migration of moisture to the surface by diffusion;
  - Capillary flow and flow due to pressure gradients caused by gravity;
  - Internal vaporization.

Humidity is the dryness of air; it is the ratio of water vapour in the air to air when it is fully saturated with water. 0% humidity means completely dry air without any water vapour and 100% humidity means the air is fully saturated with water vapour (wet air). The amount of water associated with air can be measured in terms of its absolute humidity and relative humidity. Absolute humidity is defined as the mass of water divided by the mass of dry air; it can be regarded as a measure of the moisture content of air on a dry-mass basis and it is dimensionless.

$$Absolute\ humidity = \frac{Mass\ of\ water}{Mass\ of\ dry\ air} \tag{1}$$

Relative humidity is a measure of how close the air is to being saturated at a particular temperature; it is expressed as a percentage.

$$Relative\ humidity = \frac{Absolute\ humidity\ of\ air}{absolute\ humidity\ of\ saturated\ air\ at\ the\ same\ temperature} \times 100 \quad (2)$$

Air temperature affects the relative humidity. Higher temperature will increase the ability of air to carry water vapour and more water is then needed to saturate the air. There are two types of temperature:

- *Dry bulb temperature.* Temperature is measured using a thermometer bulb.
- *Wet bulb temperature.* Temperature is measured using a thermometer bulb and surrounded by a wet cloth. Heat is removed by evaporation of the water from the cloth and the temperature measured will be lower than dry bulb temperature.

The difference between dry bulb temperature and wet bulb temperature is used to find the relative humidity of air on the psychrometric chart. The psychrometric chart is useful for finding changes in the air during drying as well as the efficiency of a drier.

Air at ambient humidity and temperature can be used for a drying process with a lower drying rate than heated air. Basically, by heating up the ambient air, we are in fact also drying it and decreasing the air humidity. Afterwards the less humid air affects the drying rate, for it can pick up more water content from the products to be dried.

2.2. Food drying process

Drying activity is one of the oldest methods for preserving food; it involves the transfer of energy (heat), either to or from the food. The nutritional quality, colour, flavour and texture of dehydrated foods are slightly less than fresh foods when it is carried out correctly, but if not there can be a greater loss of nutrition and quality, and there is a risk of microbial spoilage and the possibility of food poisoning. Drying processes are generally done using heated or hot and dry air. To gain results more effectively the hot air should be dry and moving.

The main inter-related factors which control the capacity of moisture removal from food are:

- Amount of vapour already carried by the air (absolute humidity or RH);
- Air temperature;
- Amount of air passing through the product (amount and velocity).

Water in food. The amount of water in food can be expressed on either a wet-mass basis or a dry-mass basis.

- Wet-mass basis (the sample mass can be made up of water and the dry matter of solids):

$$Moisture\ content = \frac{Mass\ of\ water}{Mass\ of\ sample} \times 100 \quad (3)$$

$$Moisture\ content = \frac{Mass\ of\ water}{Mass\ of\ water + solids} \times 100 \quad (4)$$

- Dry-mass basis:

$$Moisture\ content = \frac{Mass\ of\ water}{Mass\ of\ solids} \tag{5}$$

Water activity in food (a_w). Water plays a very important part in the stability of fresh, frozen and dried foods; it acts as a solvent for chemical, microbial and enzymatic reactions. Water activity is a measure of the availability of water to participate in such reactions. Values range from almost 0 for dried foods through to 1.0 for foods in which water is readily available, such as fresh fruit, vegetables, meat, fish and milk. Water activity is the ratio of the vapour pressure exerted by the food to the saturated vapour pressure of water at the same temperature.

$$a_w = \frac{Vapor\ pressure\ of\ water\ exerted\ by\ food}{Saturated\ vapor\ pressure\ of\ water\ at\ the\ same\ temperature} \tag{6}$$

2.3. Type of drier

There are many types and techniques for drying; the most common drying methods are (Barbosa-Cárnovas and Vega-Mercado, 1996):

- *Sun drying.*
- *Vacuum driers.* They are used for processing heat sensitive products (Spotts and Waltrich, 1977; Geankopolis, 1983). Heat transfer occurs through conduction and radiation.
- *Drum driers.* They consist of hollow metal cylinders that rotate on horizontal axes and are heated internally by steam, hot water, or other heating medium, suitable for slurries or pastes in fine suspension and also for solutions (Geankopolis, 1983).
- *Batch driers.*
  - *Kiln drier* - suitable for drying grains, fruits and vegetables. It consists of a two-story building with a slotted floor that separates the drying section with burners in the lower floor and the product on the slotted floor.
  - *Cabinet or tray drier* - usually used in small-scale and pilot plant scale operations for drying fruits and vegetables. The drier consists of an insulated cabinet, trays and a heat source for circulating the heated air.
  - *Rotary drier/agitated drier* - suitable for drying solids that are free-flowing and granular. The housing enclosing the process is stationary, while solids are moved by an internal agitator. Rotary driers represent the oldest and the most common high volume drier used in industry and more adaptations have evolved of the technology than for any other drier classification.
- *Continuous driers/belt driers.*
  - *Tunnel drier* - consists of a cabinet equipped with rails to move the tray truck along the drying chamber.
  - *Belt or conveyor drier* - the principle in a belt drier is similar to that of a tunnel drier, except that the product is conveyed through the system on a belt (Brennan et al., 1990; Okos et al., 1992).
- *Steam driers.* Although it is an alternative drying method for food processing in a high-temperature operation, most applications are for drying wood, wood products, paper and coal as noted by Kumar and Mujumdar (1990).
- *Heat pump.* It can be used in the drying of solid foods and low concentrations of liquids. The heat pump extracts heat energy from a source at low temperature and makes it available as useful heat energy at a higher temperature (Heap, 1979).
- *Spray drying.*

- *Microwave drying.* Microwaves are high-frequency waves, where the energy strikes an object and is reflected, absorbed, or transmitted through the object.
- *Freeze drying.*
- *Extrusion cooking.*
- *Fluidized-bed driers.* They are used in the dairy, food and pharmaceutical industries, suitable for products between 20 μm and 10 mm to avoid excessive channelling and slugging with a narrow particle size and regular shape. Food particles are fluidized when the pressure drop across a particle bed balances the weight of the particles and the bed expands.
- *Pneumatic driers.* They are used for drying granular, flaky or powdery products. Heated air carries the product through the drying zone and into separation units. A pneumatic drying facility consists of a hot air source, a material feeding device, the main drying chamber, a cyclone for material-air separation and a fan.

2.4. Principle of copra drying

Copra is the dried meat, or kernel, of the coconut. The name copra is derived from the Malayalam word *kopra* for dried coconut. Coconut oil is extracted traditionally by grating or grinding copra, then boiling it in water. It was developed as a commercial product by merchants in the South Seas and South Asia in the 1860s. Nowadays, the process of coconut oil extraction is done by crushing copra to produce coconut oil, and the by-product is known as cake (Wikimedia Foundation Inc., 2006).

Fresh coconut meat contains between 50 and 55% water, most of which is removed during the drying process, to yield a product containing less than 7% moisture. Drying must be carried out as quickly as possible, since coconut meat deteriorates very rapidly, being an excellent substrate for the growth of moulds and bacteria. There are three drying methods that are generally in use:

- *Sun drying.*
- *Smoke curing* or drying over an open fire in a drier or kiln, where the resultant combustion gasses come into contact with the drying coconut meat.
- *Indirect hot-air drying*, where the combustion gases do not come into direct contact with the drying coconut meat.

To obtain maximum copra and oil recovery, nuts must be harvested at fully ripe age from 11 to 12 months. Immature nuts will produce rubbery copra with low oil recovery. Rubbery copra is also susceptible to insect and mould attack due to its high moisture content (Punchihewa, 2006). If the drying process is carried out at too high a temperature, it can cause hardening; the texture of the meat will alter and the colour changes to brown.

Copra with a moisture content of 5-7% should be brittle and break easily. Another rough test of the moisture content is to light a thin slice with a match; if it burns readily, the moisture content is less than 7%, but if the flame splutters, it has a 7-10% moisture content. Above 10% moisture content, the copra burns with difficulty, and at high moisture content it will not burn at all (Grimwood, 1975).

2.5 Temperature in the drying chamber

High temperature may cause case hardening and burnt patches while low temperatures may help mould growth due to extended drying time. Supratomo et al. (1990) reported that the higher the temperature, the shorter the drying time. At 60°C, it takes 55 hours to dry copra to a final moisture content of 6%. If the temperature is increased to 70°C, the drying time is reduced to 43 hours. This phenomenon is due to the increase of the drying power of drying air which has a high influence on the drying rate, especially at high moisture content levels.

3. DESCRIPTION OF WORK

3.1. Data collection method

The data which was used for writing this project is taken from various data sources, from real environmental data, literature, and some experimental data. Environmental and coconut data were taken from PT Pertamina (Persero) AG Lahendong. The data and type of drier used were adopted from a UNU-GTP lecture handout about fish drying in Iceland. Experiments were conducted in Icelandic Fisheries Laboratories to find out the drying rate of coconut and the data used for drier design. Other data were collected from literature and the internet.

3.2. Copra drying experiments

Experiments to obtain the drying rate of copra were conducted in the Icelandic Fisheries Laboratories, in an electric oven with controlled temperature as close as possible to the drying unit design. Coconut trees do not exist in Iceland. Fortunately, there were several coconut fruits sold in a big supermarket in Iceland, so the drying rate experiment still could be done. There were some differences between coconuts found in Indonesia and those in markets in Iceland. Indonesian coconuts are bigger and weigh more. Another factor was that the husk of the coconut from the supermarket had been removed, which means the coconut had been directly exposed to ambient air conditions for a long time; this condition decreases the humidity of the coconut.

The experiments were conducted on a coconut that had been cut into two halves. Each half was weighed to find the initial coconut weight, and then dried in the electric oven at a certain temperature between 60-70°C. In the first period of drying the coconut was scaled every hour while the weight was going down rapidly. After that, scaling intensity was based on the drying rate. During the drying process, temperature and moisture content were constantly monitored and logged by the data logger. The coconut weight curve during the drying process can be seen in Figure 3. The first coconut was dried at a temperature of 70°C at around 11% initial drier humidity ratio. The second coconut was dried at a temperature of 60°C at around 25% initial drier humidity ratio. Special conditions were made for coconut number 3. It was dried at temperature 60°C with additional water cups inside the drier to obtain increased initial humidity closer to a real drier design condition, which when loaded with more than one coconut, would have higher initial drier humidity or around 40%.

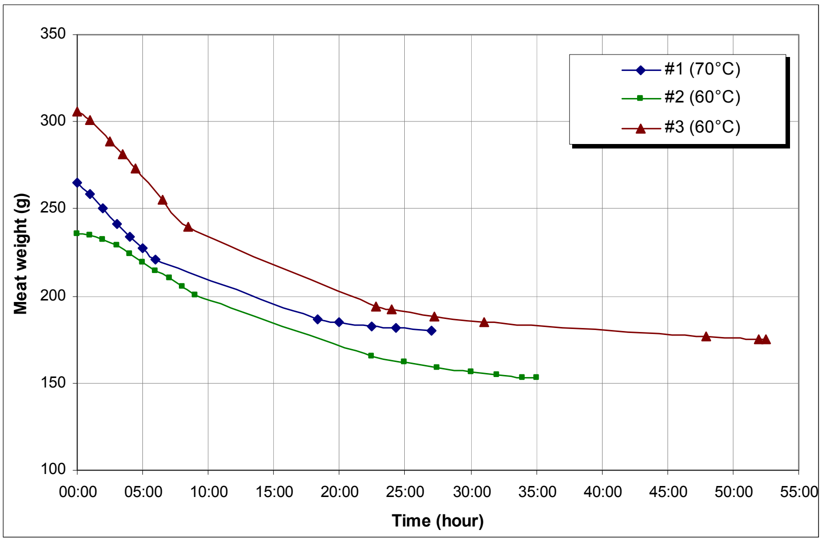

FIGURE 3: Coconut weight during the drying process

Initial coconut moisture content (%) can be calculated by drying the coconut completely (until there is no water existent). From the evaporated water (comparing the coconut weight before and after completely drying the coconut), we can find the initial moisture content. Coconut moisture content (%) was calculated using a wet basis system. Free moisture content (X) was calculated using a dry basis system. The drying rate curve can be calculated with of the following formulae:

Drying rate (R) adopted from Geankoplis (1983) and Soriao (1987):

$$R = -\frac{Ls}{A} \times \frac{dX}{dt} \qquad \rightarrow \qquad R = -\frac{Ls}{A} \times \frac{\Delta X}{\Delta T} \tag{7}$$

$$\Delta X = X_{T+\Delta T} - X_T \tag{8}$$

$$X_T = \frac{\text{Wet matter at time } T}{\text{Dry matter at time } T} \tag{9}$$

where Ls = Weight of dry product;
A = Exposed surface area for drying
$\frac{\Delta X}{\Delta T}$ = The difference of free moisture content for every given change in time
X_T = Free moisture content at time T
ΔX = The difference of free moisture content

To calculate the exposed surface area of the coconut during the drying process, the formula of sphere surface area, ($4\pi\ r_i^2$) was used, with the coconut's inside radius being the radius of the sphere. Because the coconut was cut into two halves, there is an additional surface area for each half exposed during the drying process, the thickness area of the coconut ($\pi\ r_o^2$ - $\pi\ r_i^2$) where r_o and r_i are the outside and inside radii of the coconut meat, respectively. Thus, we can calculate exposed surface area of the coconut:

$$A = 4\pi\ r_i^2 + 2\left(\pi r_o^2 - \pi\ r_i^2\right) \tag{10}$$

The calculated drying rate results of the three coconuts dried can be found in Table 1 and the drying rate curve can be found in Figure 4. The drying rate and moisture content curves in Figure 4 have similar pattern as the ideal drying rate and moisture content curves shown in Figure 2. The flat curve for the constant drying rate period cannot be plotted on these results because data was not collected during the night time. On the other hand, for different air humidity even with the same air temperature, the drying rate would be similar because air with less humidity can pick up more moisture from the product. On the moisture content vs. time curve, it is clearly shown that with higher temperature we will have a faster drying process. The temperature 60°C was chosen as the design temperature in order to prevent any case hardening of the products.

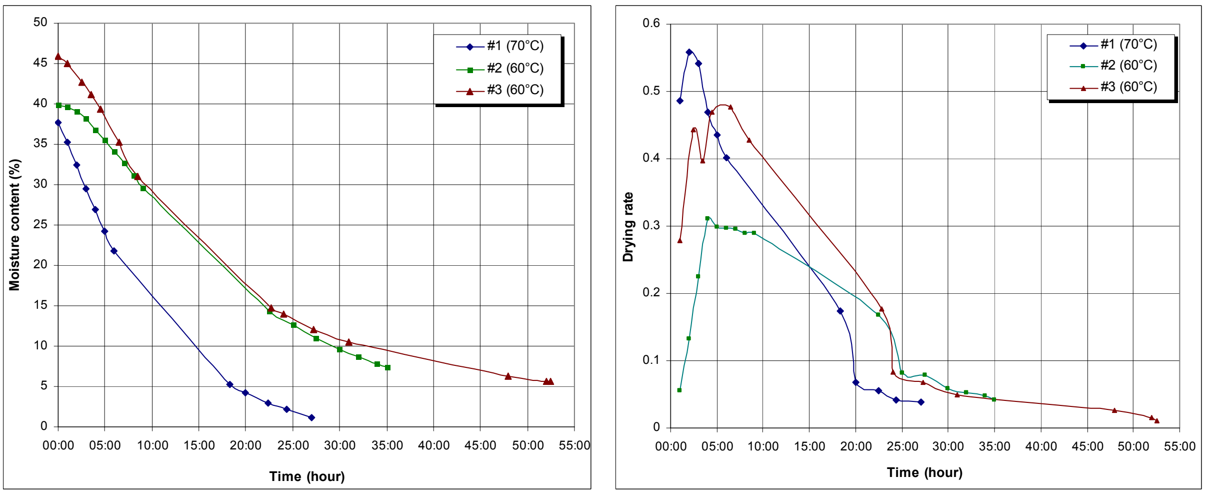

FIGURE 4: Drying rate and moisture content curves during the drying process

TABLE 1: Drying rate calculation results

No	Time (hour)	Meat weight (g)	Weight loss (g)	A (m^2)	ΔT (hour)	X	ΔX	ΔX/ΔT	Ls/A	R	Moist. content (%)
Coconut #1 dried with 70°C	00:00	264.65	0.00	0.0196	0.00	0.61	0				37.72
	01:00	258.53	6.12	0.0196	1.00	0.55	-0.05	-0.0528	9.20437	0.49	35.24
	02:00	250.15	8.38	0.0196	1.00	0.49	-0.06	-0.0607	9.20437	0.56	32.43
	03:00	241.74	8.41	0.0196	1.00	0.43	-0.06	-0.0588	9.20437	0.54	29.54
	04:00	234.38	7.36	0.0196	1.00	0.38	-0.05	-0.0510	9.20437	0.47	26.89
	05:00	227.43	6.95	0.0196	1.00	0.33	-0.05	-0.0473	9.20437	0.44	24.28
	06:00	220.95	6.48	0.0196	1.00	0.29	-0.04	-0.0437	9.20437	0.40	21.73
	18:20	186.63	34.32	0.0196	12.33	0.06	-0.23	-0.0188	9.20437	0.17	5.21
	20:00	184.88	1.75	0.0196	1.67	0.05	-0.01	-0.0073	9.20437	0.07	4.17
	22:25	182.78	2.10	0.0196	2.42	0.03	-0.01	-0.0060	9.20437	0.06	2.91
	24:20	181.53	1.24	0.0196	1.92	0.02	-0.01	-0.0044	9.20437	0.04	2.16
	27:00	180.00	1.53	0.0196	2.67	0.01	-0.01	-0.0041	9.20437	0.04	1.18
Coconut #2 dried with 60°C	00:00	235.36	0.00	0.0170	0.00	0.66	0.00				39.90
	01:00	234.49	0.87	0.0170	1.00	0.66	-0.01	-0.0062	8.99728	0.06	39.68
	02:00	232.40	2.09	0.0170	1.00	0.64	-0.01	-0.0148	8.99728	0.13	39.13
	03:00	228.88	3.52	0.0170	1.00	0.62	-0.02	-0.0249	8.99728	0.22	38.20
	04:00	223.99	4.89	0.0170	1.00	0.58	-0.03	-0.0346	8.99728	0.31	36.85
	05:00	219.29	4.70	0.0170	1.00	0.55	-0.03	-0.0332	8.99728	0.30	35.50
	06:00	214.63	4.66	0.0170	1.00	0.52	-0.03	-0.0330	8.99728	0.30	34.09
	07:00	209.98	4.65	0.0170	1.00	0.48	-0.03	-0.0329	8.99728	0.30	32.63
	08:00	205.44	4.54	0.0170	1.00	0.45	-0.03	-0.0321	8.99728	0.29	31.14
	09:00	200.88	4.55	0.0170	1.00	0.42	-0.03	-0.0322	8.99728	0.29	29.58
	22:30	165.20	35.68	0.0170	13.50	0.17	-0.25	-0.0187	8.99728	0.17	14.37
	25:00	161.98	3.22	0.0170	2.50	0.15	-0.02	-0.0091	8.99728	0.08	12.67
	27:30	158.91	3.07	0.0170	2.50	0.12	-0.02	-0.0087	8.99728	0.08	10.98
	30:00	156.60	2.31	0.0170	2.50	0.11	-0.02	-0.0065	8.99728	0.06	9.67
	32:00	154.94	1.66	0.0170	2.00	0.10	-0.01	-0.0059	8.99728	0.05	8.70
	34:00	153.46	1.48	0.0170	2.00	0.08	-0.01	-0.0052	8.99728	0.05	7.82
	35:00	152.81	0.65	0.0170	1.00	0.08	0.00	-0.0046	8.99728	0.04	7.43
Coconut #3 dried with 60°C	00:00	306.00	0.00	0.0193	0.00	0.85	0.00				45.91
	01:00	300.92	5.08	0.0193	1.00	0.82	-0.03	-0.0307	9.07700	0.28	45.00
	02:30	288.80	12.12	0.0193	1.50	0.74	-0.07	-0.0488	9.07700	0.44	42.69
	03:30	281.55	7.24	0.0193	1.00	0.70	-0.04	-0.0438	9.07700	0.40	41.21
	04:30	272.99	8.56	0.0193	1.00	0.65	-0.05	-0.0517	9.07700	0.47	39.37
	06:30	255.61	17.38	0.0193	2.00	0.54	-0.11	-0.0525	9.07700	0.48	35.25
	08:30	240.00	15.61	0.0193	2.00	0.45	-0.09	-0.0472	9.07700	0.43	31.03
	22:45	194.20	45.80	0.0193	14.25	0.17	-0.28	-0.0194	9.07700	0.18	14.77
	24:00	192.30	1.90	0.0193	1.25	0.16	-0.01	-0.0092	9.07700	0.08	13.93
	27:15	188.30	4.00	0.0193	3.25	0.14	-0.02	-0.0074	9.07700	0.07	12.10
	31:00	184.90	3.40	0.0193	3.75	0.12	-0.02	-0.0055	9.07700	0.05	10.48
	48:00	176.60	8.30	0.0193	17.00	0.07	-0.05	-0.0029	9.07700	0.03	6.28
	52:00	175.50	1.10	0.0193	4.00	0.06	-0.01	-0.0017	9.07700	0.02	5.69
	52:30	175.40	0.10	0.0193	0.50	0.06	0.00	-0.0012	9.07700	0.01	5.63

After the drying process of each coconut was completed, we tried to find out the dried coconut water activity (a_w) which is measured using an a_w box instrument. Fresh coconuts have water activity of around 0.98 and dried coconuts have a different water activity; it mostly depends on the final moisture content found. The results are shown in Table 2.

TABLE 1: Water activity of the dried coconuts

Coconut no.	Dried coconut samples			
	I	II	III	Average
1	0.719	0.744	0.730	0.731
2	0.786	0.763	0.789	0.779
3	0.770	0.748	0.773	0.764

4. DRIER DESIGN

There are many kind of driers used for food drying processes; one of the most common used is cabinet or tray drier. This type of drier is usually used in small scale and pilot plant scale operations. The drier consists of an insulated cabinet, trays and a heat source for circulating the heated air (Karel, 1975). This type of drier is mainly used for drying fruits and vegetables.

4.1. Coconut data

Coconuts are usually cut into halves and water drained before they are put into the drying cabinet, complete with the shell. Coconut halves will be laid on the trays with the cup side up.
Coconut data:

- Diameter : 10 cm
- Weight : 0.5 kg
- Initial moisture content : 50%
- Final moisture content : 6%

After being cut into halves, the area needed for 1 coconut laid on the tray is:

$$\text{Area for 1 coconut} = 10\text{ cm} \times 10\text{ cm} \times 2\text{ pc} = 200\text{ cm}^2/\text{pc} = \mathbf{0.02\ m^2/pc}$$

4.2. Tray and rack data

Tray is a flat, shallow container with a raised rim used for carrying, loading and holding the coconut during the drying process. Tray dimensions should not be too wide or big to enhance ease in handling in/out of the drying unit; 1 m length by 1 m width is an easy and common size for tray dimensions.

Rack is a frame for holding the trays. The main consideration for designing rack dimensions is rack height. Rack height should give the operator access for loading and unloading the tray from the rack. In many cases in Iceland, 2.1 m is the maximum rack height used for cabinet type driers. Racks will hold the tray in stacks, so there will be the space needed between the trays. Space between the stacked trays depends on the size of the coconuts, because the height of the cut coconut is up to 5 cm. Thus, 8 cm can be used as the space between stacked trays which still gives enough space for hot air flow over the coconut. Hence:

- Tray width : 1 m
- Tray length : 1 m
- Tray base thickness : 0.02 m
- Space between trays : 0.08 m
- Tray height from floor : 0.2 m
- Max rack height : 2.1 m

Tray area is:

$$Tray\ area = Tray\ width \times Tray\ length \tag{11}$$

$$= 1 \times 1 = \mathbf{1\ m^2}$$

Coconut capacity for each tray based on tray area is:

$$Tray\ capacity = \frac{Tray\ area}{Area\ for\ 1\ coconut} \tag{12}$$

$$= \frac{1\,\mathrm{m}^2}{0.02\,\mathrm{m}^2} = \textbf{50 coconuts/tray.}$$

Number of trays stacked for every rack is:

$$\textit{Trays in to each rack} = \frac{\textit{Max rack height - Tray height from floor}}{\textit{Space between trays + Tray base thickness}} \tag{13}$$

$$= \frac{2.1\,\mathrm{m} - 0.2\,\mathrm{m}}{0.08\,\mathrm{m} + 0.02\,\mathrm{m}} = \frac{1.9\,\mathrm{m}}{0.1\,\mathrm{m}} = \textbf{19 trays.}$$

Coconut capacity for each rack is:

$$\text{Rack capacity} = \text{Trays each rack} \times \text{Tray capacity} \tag{14}$$

$$= 19 \text{ trays} \times 50 \text{ coconuts} = \textbf{950 coconuts.}$$

Optimum rack configuration is not more than 5 m along a tunnel to make the hot air distribute more evenly over the coconuts. In this case, the drying chamber is designed for 3 racks series wide and 5 rack series in length which makes 15 racks inside the drying cabinet.

Hence, the total tray capacity of the drier is:

$$\textit{Total trays} = \textit{Trays each rack} \times \textit{Total racks} \tag{15}$$

$$= 19 \text{ trays} \times 15 \text{ racks} = \textbf{285 trays}$$

Thus, the total capacity of the drier can be calculated:

$$\textit{Drier coconut capacity} = \textit{Total racks} \times \textit{Rack capacity} \tag{16}$$

$$= 15 \text{ racks} \times 950 \text{ coconuts} = \textbf{14,250 coconuts.}$$

4.3. Mass and energy balances

Mass balances

The mass balance calculations provide information about the coconut weight (mass) before and after the drying process. Theoretically, initial coconut weight is equal to the final dried coconut weight and the weight of water vapour carried out during the drying process. The drier used can handle up to 14,250 coconuts for each drying cycle; that means it will work with 7,125 kg of coconut with an average 50% water content.

The maximum mass of coconuts that can be processed by the drier:

$$\textit{Fresh coconut weight} = \textit{Drier coconut capacity} \times \textit{Average weight of 1 coconut} \tag{17}$$

$$= 14{,}250 \text{ coconuts} \times 0.5 \text{ kg} = \textbf{7,125 kg}$$

The wet matter content of 7,125 kg coconut with 50% water content is:

$$= 50\% \times 7{,}125 \text{ kg} = \mathbf{3{,}562.5 \text{ kg}}$$

The dry matter content of 7,125 kg coconut with 50% water content is:

$$= (1 - 50\%) \times 7{,}125 \text{ kg} = \mathbf{3{,}562.5 \text{ kg}}$$

If a 60°C drier temperature is used, the time needed during the experiment for drying the coconut from 46% water content to 6% water content is 52.5 hours. Supratomo et al. (1990) estimate it will need 55 hours for drying 50% water content to 6% water content. Here, 55 hours are used for the drying time because the average coconut water content in Lahendong is around 50%.

The weight of the final copra product with 6 % water content is then:

$$Dried\ coconut\ weight = \frac{Weight\ of\ dry\ matter}{100\% - Final\ moisture\ content} \tag{18}$$

$$\frac{3{,}562.5 \text{ kg}}{100\% - 6\%} = \frac{3{,}562.5 \text{ kg}}{94\%} = \mathbf{3{,}789.9 \text{ kg}}$$

$$Mass\ of\ water\ vaporized\ (\Delta m) = Fresh\ coconut\ weight - Dried\ coconut\ weight \tag{19}$$

$$= 7{,}125 \text{ kg} - 3{,}789.9 \text{ kg} = \mathbf{3{,}335.1 \text{ kg}}$$

Energy balances

Starting from an ambient air condition, the energy will be calculated both inside the drier and the exhausted air, as seen in Figure 5.

Before calculation, the following data is provided:

- Ambient temperature (T_1) : 22°C
- Humidity ratio (HR_2) : 67 %
- Ambient pressure : 92 kPa
- Drying temperature (T_3) : 60°C
- Drying humidity ratio (HR_3) : 40 %
- ρ_{air} (@ T_3 and P_{amb}) :0.8787 kg/m^3
- T_4 : 48°C

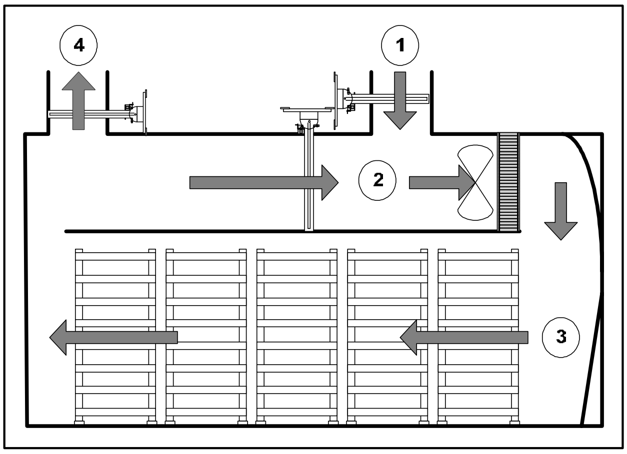

FIGURE 5: The proposed drying unit for coconuts

Exhausted air temperature (T_4) will be kept at a temperature not more than 12°C lower than the drying temperature (T_3). This condition will increase the drying efficiency because the hot exhausted air is for the drier, leading to less energy consumption. In order to prevent hardening cases on drying food, a drying humidity ratio less than 30% is not allowed; therefore, 40% is used as the drier humidity ratio.

The calculation is started by making a plot using all data that we have collected on a Mollier chart or I-x diagram. The most important information for making the plot base for the drier model and conditions are (Arason, 2006) the following:

- From data point 2 to data point 3, the air-water content is constant
- From data point 3 to data point 4, the energy (enthalpy) is constant

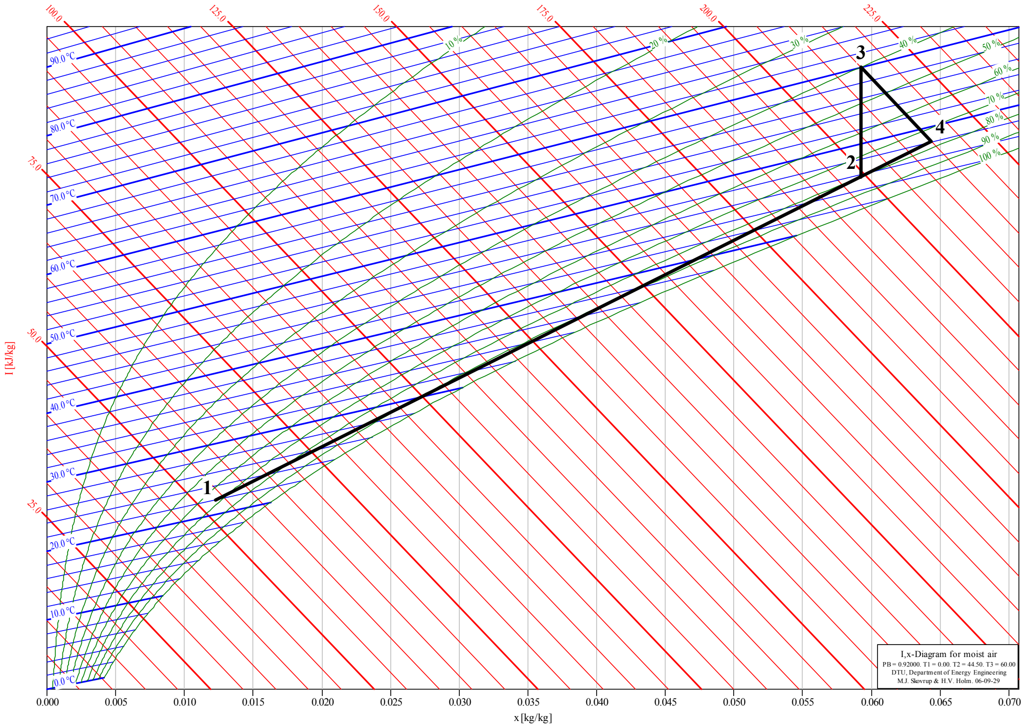

FIGURE 6: The drier data plotted on a Mollier chart

The complete drier plot is shown in Figure 6. After that we can find out the properties for each point in the drier as listed in Table 3.

TABLE 3: Properties of each drier section

Point	T (°C)	HR (%)	X (g water/kg air)	i (kJ/kg air)
1	**22**	**67**	12.21	53,19
2	45,41	81.41	59.02	198,3
3	**60**	**40**	59.02	214,6
4	**48**	77.05	64,19	214,6

Note: Bold numbers stand for data input

Based on Table 3, we can determine the total mass flow of air needed for the drying process:

$$G = \frac{\frac{\Delta m}{t}}{X_4 - X_3} \tag{20}$$

$$= \frac{\frac{3{,}335.1\,\text{kg}}{55\,\text{hours}}}{(64.19 - 59.02)\times 10^{-3}} = \frac{60.6381}{0.00517}$$

= **11,728.84 kg/h**

The volume of air needed for the drying process:

$$V = \frac{G}{\rho_{air}} \tag{21}$$

$$= \frac{11{,}728.84\ \text{kg/h}}{0.8787\ \text{kg/m}^3} = \mathbf{13{,}347.94\ m^3/h}$$

where G = Mass flow of air needed for the drying process (kg/h);
Δm = Mass of water vaporized from the fresh coconut (kg):
t = Total time of drying process (hour);
X_3 = Air water content in section number 3 of the drier (kg water/kg air);
X_4 = Air water content in section number 4 of the drier (kg water/kg air);
V = Volume flow of air needed for the drying process (m^3/h);
ρ_{air} = Density of air at specific drier temperature and air pressure (kg/m^3).

To calculate the air speed needed inside the drier, the cross-sectional area of the drier has to calculated where the air stream flows, excluding the area where the coconut and racks fill (A_{CR}). It can be roughly assumed that it is half the area of the drier cross section, width by height, as calculated below:

$$A_{CR} = \frac{\textit{Drier width} \times \textit{Drier height}}{2} \tag{22}$$

$$= \frac{3\ \text{m} \times 2.1\ \text{m}}{2} = \mathbf{3.15\ m^2}$$

Air speed requirement over the coconut for removing the moisture is determined by:

$$v = \frac{V}{A_{CR}} \tag{23}$$

$$= \frac{13{,}347.94\ \text{m}^3\text{/h}}{3.15\ \text{m}^2} = 4{,}237\ \text{m/h} = \mathbf{1.17\ m/s}$$

The heat requirement for the drying process (q) is calculated by:

$$Q = G \times (i_3 - i_2) \tag{24}$$

$$= 11{,}728.84\ \text{kg/h} \times (214.6 - 198.3)\ \text{kJ/kg} = \mathbf{191{,}180\ kJ/h}$$

where A_{CR} = Cross-sectional area of the drier (m^2);
v = Air speed requirement for the drying process (m/h);
Q = Heat requirement for the drying process (kJ/h);
i_2 = Air enthalpy in section number 2 of the drier (kJ/kg air);
i_3 = Air enthalpy in section number 3 of the drier (kJ/kg air).

4.4. Selection of heating element (radiator)

Heating elements are the heart of a drying unit, a transferring energy from thermal water to air. Then the heated air will use the energy to evaporate water content from the product during the drying process. The heating element is a radiator (fluid-air heat exchanger) constructed from a tube with or without a fin where the thermal water flows inside. Fin and tube radiators also make it possible to use fans (blowers) to drive the hot air across the product more evenly. The heater should have the capability to supply and transfer the energy from hot water into the drying chamber as needed for the drying process.

There are many radiator manufacturers. The most suitable product can be chosen based on design calculations made before and, of course, depends on the availability of radiators in the local market. Lahendong geothermal field produces brine water with a high silica content (silica saturation index 1.3); this means that the potential for silica precipitation occurring inside the radiator tube is high. Special material for the radiator and chemical treatments should be applied during the operation to minimize the silica deposition process. Just for pre-calculation, we can assume radiator properties as listed below; for future real calculations, the radiator properties should be based on the product availability in the local market.

Radiator properties

T_{in} = 95°C
T_{out} = 80°C
ΔT = 15°C

The mass flowrate of brine water can be calculated from the heat formula below:

$$Q = mc\Delta T \tag{25}$$

or,

$$m = \frac{Q}{c\,\Delta T} \tag{26}$$

$$= \frac{191{,}180\ \text{kJ/h}}{4.2\ \text{kJ/kg°C} \times 15\ \text{°C}} = \mathbf{3{,}034.6\ kg/h}$$

where Q = Heat requirement for the drying process (kJ/h);
m = Mass flowrate of brine water for the drying process (kg/h);
c = Specific heat of water (kJ/kg °C);
ΔT = Temperature difference between radiator inlet and outlet (°C).

4.5. Selection of fan

Selecting a fan mostly depends on the volume of air needed during the drying process. From the volume of air needed and the fan drop pressure, the minimum fan power required can be calculated and then the fan models and types can be chosen from a fan manufacturer's catalogue. Generally in drying design, the value of the fan drop pressure is set at 450 Pa. The main relationships are:

$$P_{fan} = \frac{G\Delta p}{\eta_{fan}} \tag{26}$$

$$P_{motor} = \frac{P_{fan}}{\eta_{motor,fan}} \tag{27}$$

where P_{fan} = Fan power (W);
P_{motor} = Motor power (W);
Δp = Pressure drop (Pa);
G = Volume of air needed (m^3/s);
η_{fan} = Efficiency of fan;
$\eta_{motor\,fan}$ = Efficiency of fan motor.

Based on the previous calculation, 13,348 m^3/h of circulated air are needed during the drying process. To get this volume rate, the right fan has to be chosen. Using the catalogue from Nuaire Fan Solution, the most suitable fan performance data is:

Fan code	: BX63E22GZ4.5
Actual duty	: 13,951 m^3/h at 491 Pa @ 60°C
Fan efficiency	: 67% @ 60°C
Fan speed	: 2,910 / 1,460 rpm
Blade angle	: 30°
Motor phase	: 3
Motor power	: 4.5 / 1.3 kW

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

- Brine water gained from a production separator still carries large amounts of energy which can be extracted. It is a good utilization to use the heat for a crop drying process. Brine water with temperatures up to 99°C has more than enough heat for a 60°C drying unit. Temperature and humidity has to be maintained inside the drying unit to achieve the optimum conditions for the drying process, so that problems such as surface hardening and microbial spoilage can be avoided. The dried air from the drying chamber can be re-circulated until it reaches the maximum humidity ratio. Using this method requires less energy for heating up than using 100% fresh air intake. The re-circulated air can be controlled by valves or a window as shown in Figure 5.
- Using a tray drier of known dimensions (see Section 4.2) it is possible to process 14,250 coconuts for every cycle of the drying process, consuming 3,035 kg/h brine water (depending on the efficiency of the radiator). The production separator produces up to 40,000 kg of brine every hour. This means that a large number of coconuts and other crops can be dried depending on market conditions.
- Optimistically 159 drying cycles of the drying process could be performed every year, which means that if 14,250 coconuts are dried per drying cycle, 2,265,750 coconuts could be handled by this drying unit every year.
- The drying process can be performed without using a fan, but of course then it could not maintain an evenly distributed temperature inside the drier. Using a fan, we can remove the moisture content faster.
- A high silica saturation index of the geothermal fluid means we must use some sort of silica inhibitor, in order to ensure that the drying unit runs normally.

5.2 Recommendations

This drying unit needs further field operation tests to achieve the optimum drying operation, for both the yielded copra quality and the reliability of the drying unit itself. The drier's parameters during the drying process can be accommodated later to get optimal results.

Injecting pressurized steam regularly through the radiator to clean out possible silica sediments should help in preventing silica scaling.

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