

Design of Tomato Drying System by Utilizing Brine Geothermal

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Abstract. Cultivation of tomato plants in Indonesia has been started since 1961. Tomatoes generally will rot in three days if left on storage. Moreover, low quality tomatoes have cheaper price. After harvested, tomatoes need to be treated by drying process so it can last longer. Energy for drying tomatoes can be obtained by utilizing heat from geothermal brine. Purpose of this research is to design a tomato drying system by extracting heat of geothermal brine from separator with certain flow rate to heat up water by using a heat exchanger. Furthermore, this water will be used to heat up the surrounding air which is circulated by blower system to heat up the tomatoes chamber. Tomatoes drying process needs temperature range of 50-70°C to evaporate water content from 95.7% to 26%. After that treatment, the tomatoes are expected to have better durability. The objective of this study is to determine the quantity of hot brine which is needed for drying tomatoes and to design a drying system so that tomatoes can last longer.

1. Introduction

Most geothermal fields in Indonesia are high temperature - liquid dominated systems with high flow rates. By using single flash method on those conditions, brine from separator will be injected directly back to reservoir. However, brine as residual product with temperature 175-190°C (based on cumulated data from geothermal fields in West Java) can be utilized for direct use application such as for tomato drying process. One of these by using the potential of brine is for tomato drying. This paper will discuss drying tomatoes by using hot brine from the separator.

2. Methods

This study was conducted by collecting information from research of Andritsos and Ehiem [2009], who explained information about geothermal direct use, characteristic of tomato and fruit dryer. Based on those data, some assumptions were collected to calculate mass flow rate of brine needed for drying tomatoes.

3. Drying Tomatoes

In Indonesia, tomato (*Lycopersium esculentum*) is a kind of fruit that can be harvested a whole year long. Cultivating tomatoes has been prioritized since 1961 to fulfill daily needs [4]. Tomatoes grow in lowland and highland areas, but they cannot survive for a long period of time after harvested. After three days in storage, tomatoes respiration and transpiration will cause increase of CO₂ and H₂O content [4]. It will trigger the growth of bacteria that will cause tomato rotting.



The quality of tomatoes really depends on its freshness. Low water content of tomatoes discourage the growth of bacteria. In order to make the tomatoes last longer after harvesting, preservation method is needed to drying tomatoes while retaining flavor. Dried tomatoes are usually consumed in Nigeria, USA, Greece as processed food and sweetmeat which packed with nutrients that deliver health benefits. In Indonesia, tomatoes are usually not dried after harvesting. It causes tomatoes to become rotten and thrown away before them can be sold.

The drying process requires heat to decrease the moisture content from a tomato. Normally, drying process is conducted by exposing tomato to the sun. On the other hand, artificial drying is done by using engineered equipments. This study will be conducted by using artificial drying system with heat taken from geothermal brine. The heat will use to increase the working fluid's temperature. In this process, fresh air will be heated by working fluid (water) and then circulated into the drying room. At this system, temperature, cleanliness, and the drying process can be controlled to get the optimum, continuous, and faster dryness.

Once harvested, the tomatoes are sorted, washed, and cut into several pieces. This treatment can accelerate the decline of tomato's moisture content by evaporation. During the drying process, texture, color, and flavor of the tomatoes will change. However, their nutritional value still can be preserved by selecting the optimum drying conditions[2].

The desirable moisture content of tomatoes is 26% [5]. This condition is very stable so that does not easily change the taste and resistant to microorganisms, especially fungi.

4. Tomatoes Drying System By Using Brine

A drying process using hot air requires heat for increasing the air temperature in order to reduce the relative humidity of the air. These sources included solar energy, fuel, or geothermal. In this study, the heat comes from residual fluid of geothermal energy. The heat will heat up fresh water, then the heat from circulated fresh water will heat up the air inside the drying room. Hot air in the drying room will absorb the moisture of the tomatoes. The room temperature of tomatoes dryer is based on the standard condition which is determined by a number of cumulated data from geothermal fields in West Java.

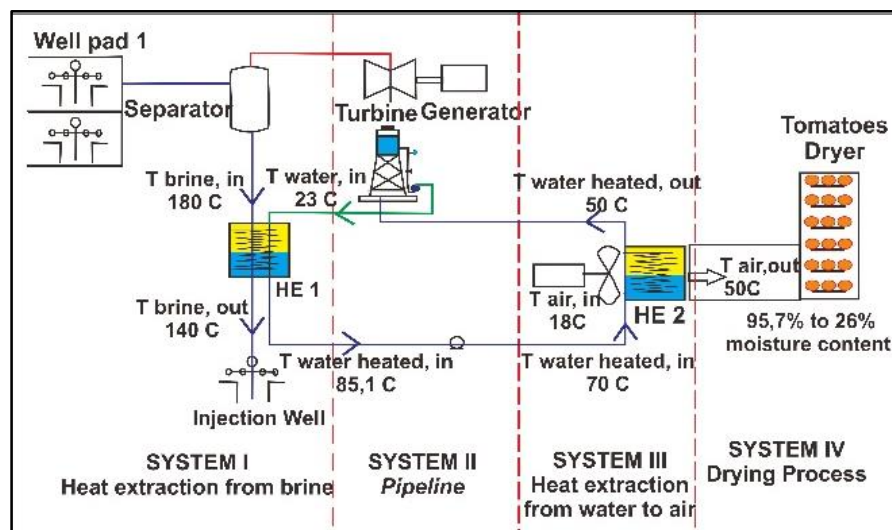


Figure 1. Schematic of tomatoes drying system.

Figure 1 is a schematic of a tomato drying system using geothermal brine. It consists of four systems, heat extraction from brine (system I), fresh water circulation inside pipeline of approximately 2 km long (system II), heat extraction from water to air (system III), and drying process (system IV). Fresh water is heated by geothermal brine through first heat exchanger (HE1). Then, hot water is transferred to the location of tomatoes dryer. The heat extracted from the heated water in pipeline is used to warm the air

inside the drying room through a blower in the second heat exchanger (HE2). Next, hot air will absorb moisture from the tomatoes in drying room. After that, the hot water will continue to circulate from HE2 towards HE1 through a pipeline. Those process are shown in Figure 2.

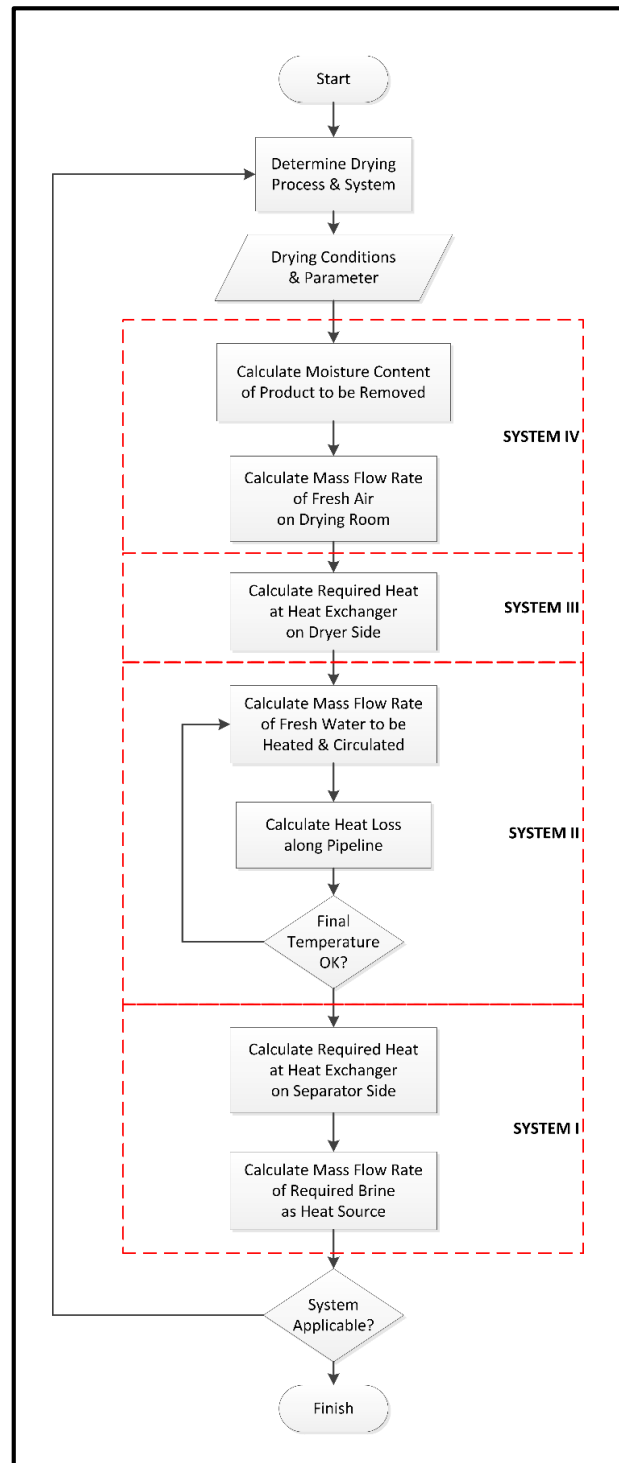


Figure 2. System design flow chart.

To calculate the mass flow rate of brine which is needed to dry the tomatoes, some parameters will be assumed and used as a constant in those four systems:

- the capacity of the dryer is 1 ton per day of tomatoes. This amount is obtained from total of tomato production in West Java for one year. Tomatoes produced in West Java are about 304.687 tons or about 835 ton/day [3]. And then, that amount is divided by the total area of tomato garden, which is about 15 hectares. Actually, the number of harvested tomatoes is more than 1 ton/day.
- the distance and elevation difference between heat source (brine location) and drying location are about 2 kilometers and 110 meters. These values are estimated by observing the topography in West Java.
- fresh water is circulated by using 3 inch carbon steel pipe.
- the drying room temperature is 50°C.
- the ambient temperature around drying room is 18°C.
- the favorable relative humidity of product in system IV is 26% [5].
- the efficiency of heat exchanger in system III is 84% [5].

The time needed to reduce the moisture content to 26% by flowing hot air into the drying chamber is 14 hours. The moisture content to be removed is calculated using Equation (1):

$$M_r = M * \left(\frac{RH_1 - RH_2}{1 - RH_2} \right) \quad (1)$$

Where, M is drying capacity (kg)

M_r is moisture to be removed (kg)

RH_1 is initial relative humidity (%)

RH_2 is final relative humidity (%)

Table 1. Moisture content to be removed [5].

Parameter	Symbol	Value	Unit
Drying capacity	M	1000	kg
Drying time	t	14	hours
Initial humidity	RH_1	95.7%	
Final humidity	RH_2	26%	
Moisture of product to be removed	M_R	941.9	kg

Tomatoes drying system occurs through two processes of energy usage, namely heating and drying by the following Equations(2) - (5).

$$Q_{dryer} = Q_{heatup} + Q_{evaporate} \quad (2)$$

$$Q_{heatup} = m_p c_{pp} (T_{fin} - T_{in}) \quad (3)$$

$$Q_{evaporate} = M_r * h_{fg} \quad (4)$$

$$h_{fg} = h_v - h_l \quad (5)$$

Where, Q_{dryer} is total heat required for dryer process (kW)

$Q_{heat-up}$ is heat required for heat up tomato (kW)

$Q_{evaporate}$ is heat required for decreasing moisture content (kW)

h_{fg} is heat laten of moisture (kJ/kg)

C_p is heat capacity of product (kJ/kg°C)

m_p is mass rate of product (kg/s)

$T_{f, in}$ is final temperature (°C)

$T_{f,in}$ is initial temperature (°C)

Based on the Equations (2) – (5), Table 2 shows calculation of demand of total heat:

Table 2. Total heat required for drying process.

Parameter	Symbol	Value	Unit
Tomato heat capacity	C_{pp}	4.6	kJ/kg.°C
Initial temperature of product	$T_{p,in}$	18	°C
Required temperature of product	$T_{p,fin}$	50	°C
Heat latent of moisture	h_{fg}	2420.3	kJ/kg
Required heat for heat up	Q_{hu}	2.92	kW
Required heat for evaporation	Q_{ev}	45.2	kW
Total heat required for drying process	Q_{net}	48.2	kW

The value of moisture content is taken from Psychrometric diagram. The demand of drying air flow rate can be calculated by Equation (6) and (7):

$$M_a = \left(\frac{M_r}{Hr_1 - Hr_2} \right) \quad (6)$$

$$m_a = \frac{M_a}{t} \quad (7)$$

Where, M_a is required mass of drying air (kg)

M_r is moisture to be removed (kg)

Hr_1 is initial humidity ratio

Hr_2 is final humidity ratio

m_a is mass flow rate of drying air (kg)

t is drying time (s)

Based on the Equation(6) and (7), Table (3) shows demand calculation of total heat and mass flow rate of drying air:

Table 3. Mass flow rate of drying air.

Parameter	Symbol	Value	Unit
Atmospheric pressure	P_{atm}	1	atm
Ambient temperature	T_a	18	°C
Relative humidity inside drying room	RH_{dr}	35%	
Drying room temperature	$T_{u,fin}$	50	°C
Initial humidity ratio	$H_{r,1}$	0.005	kg/kg
Final humidity ratio	$H_{r,2}$	0.028	kg/kg
Required mass of drying air	M_a	40,9	kg
Mass flow rate of drying air	m_a	0.81	kg/s

Based on the calculation of system IV, the value of mass flow rate of drying air which flows to HE in system III can be used to obtain the mass flowrate of fresh water. The type of heat exchanger material selected is brazed plate heat exchanger. It consists of two plates that are combined into a pressed plate

[6]. By using the energy balance of Equation (8), the output temperature and heat exchanger area can be determined:

$$\begin{aligned} Q_i &= \eta \times [m_f \times c_p \times (T_{in} - T_{out})]_{heater} \\ &= [m_f \times c_p \times (T_{out} - T_{in})]_{heated} \end{aligned} \quad (8)$$

Where, Q_i is heat required for heating (W/m^2)

m_f is mass flow rate of fresh water (kg/s)

C_p is specific heat capacity of fluid ($J/Kg^{\circ}C$)

T_{in} is fluid temperature in heat exchanger inlet ($^{\circ}C$)

T_{out} is fluid temperature in heat exchanger outlet ($^{\circ}C$)

LMTD (Logarithmic Mean Temperature Difference) is average temperature difference along the heat exchanger. In counter flow heat exchanger, the inlet temperature difference between hot fluid and cold fluid is always greater than the outlet temperature. So, that its the temperature of hot fluid decreases and cold fluid increases. Therefore, to achieve greater heat recovery, a counterflow design is preferred to that of a drying design. LMTD can be calculated based on the change of temperature between the two types of fluid which flow into the heat exchanger[1]. LMTD can be calculated using Equation (9):

$$LMTD = \frac{(T_{hot\ in} - T_{cold\ out}) - (T_{hot\ out} - T_{cold\ in})}{\ln\left(\frac{T_{hot\ in} - T_{cold\ out}}{T_{hot\ out} - T_{cold\ in}}\right)} \quad (9)$$

The next step is to calculate the heat exchanger area with Equation(10):

$$Q = U \cdot A \cdot LMTD \quad (10)$$

Where, U is overall heat transfer coefficient ($W/m^2.K$). The typical value of U for water-to-water and water-to-air type heat exchanger are $2000\ W/m^2.K$ and $600\ W/m^2.K$ respectively (Leinhard, 2008)

A is heat transfer area (m^2)

LMTD is Logarithmic Mean Temperature Difference (K)

Table 4 shows the values in system III that are calculated by using the Equations (8) – (10).

Table 4. Calculation of water and air of heat exchanger in system III.

Parameter	Symbol	Value	Unit
Temperature water in	$T_{w,in}$	70	$^{\circ}C$
Temperature water out	$T_{w,out}$	50.0	$^{\circ}C$
Heat capacity of water	C_{p_w}	4.197	$kJ/kg^{\circ}C$
Massa water	M_w	2.8	kg/s
Temperature air in	$T_{a,in}$	18	$^{\circ}C$
Temperature air out	$T_{a,out}$	50	$^{\circ}C$
Heat capacity of air	C_{p_a}	1.008	$kJ/kg^{\circ}C$
Heat exchanger efficiency	η_{HE}	84%	-
Mass flow rate of air	$\dot{m}_a$	0.813	kg/s
Required heat	Q	48.15	kW
Logarithmic Mean Temperature difference	LMTD	25.5	K
Area	A	3.14	m^2

In order to produce an outlet temperature of 70°C when the fresh water is entering HE2, the pipe must be designed by minimum heat loss. Heat transfer which occur along the pipe until entering station of the heat exchanger were dominated by two process, which are conduction and convection (Figure3).

The following data are the required heating water flow rate and type of pipe material and its insulation that will be used to calculate outlet temperature of 70°C as listed on Table 5.

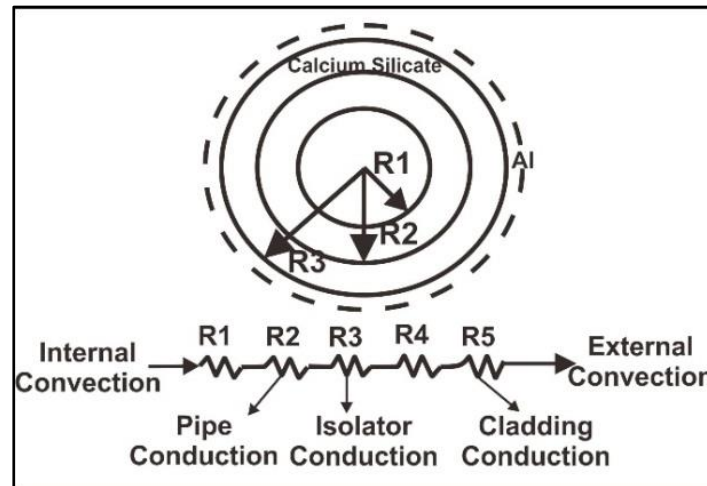


Figure 3. Schematic of heat transfer along the pipeline.

Table 5. Calculation of heat loss along the pipeline (system II).

Parameter	Symbol	Value	Unit
Final fluid temperature	T_{fin}	70	$^{\circ}\text{C}$
Ambient temperature	T_{∞}	18	$^{\circ}\text{C}$
Wind velocity	v_a	2	m/s
Mass flow rate of water	$\dot{m}_w$	2.84	kg/s
Fluid velocity	v_w	1.0	m/s
Cross section area of pipe	A_c	0.003	m^2
Inside pipe diameter	D_i	0.0762	m
Pipe length	L	2000	m
Radius of inside pipe	R_1	0.038	m
Radius of outside pipe	R_2	0.048	m
Radius of outside insulation	R_3	0.058	m
Radius of outside cladding	R_4	0.063	m
Thermal conductivity of pipe	R_p	71.52	$\text{W/m}^{\circ}\text{C}$
Thermal conductivity of insulation (Calcium Silica)	k_i	0.05	$\text{W/m}^{\circ}\text{C}$
Thermal conductivity of Al cladding	k_c	227	$\text{W/m}^{\circ}\text{C}$
Initial fluid temperature	$T_{w,in}$	85.1	$^{\circ}\text{C}$
Heat Loss Total	Q_{loss}	179.85	kW
Initial fluid temperature	$T_{w,in}$	85.1	$^{\circ}\text{C}$

Based on the calculation of heat loss in system II and final temperature which maintains to 70°C , outlet temperature and mass flow rate of required brine can be obtained as shown in Tabel 6.

Table 6. Calculation of brine and fresh water of heat exchanger in system I.

Parameter	Symbol	Value	Unit
Temperature brine in	$T_{b,in}$	180	°C
Temperature brine out	$T_{b,out}$	140	°C
Mass flow rate of brine	M_b	7	kg/s
Heat capacity of brine	$C_{p,b}$	4.4	kJ/kg °C
Temperature water in	$T_{w,in}$	23	°C
Temperature water out	$T_{w,out}$	85.06	°C
Heat capacity of water	$C_{p,w}$	4.2	kJ/kg °C
Heat exchanger efficiency	η_{he}	60%	-
Mass flow rate of water	M_w	2.8	kg/s
Total heat required (for heating fresh water)	Q_w	741.2	kW
Logarithmic Mean Temperature difference	LMTD	105.5	K
Area	A_{HE}	3.5	m ²

5. Drying Room Design

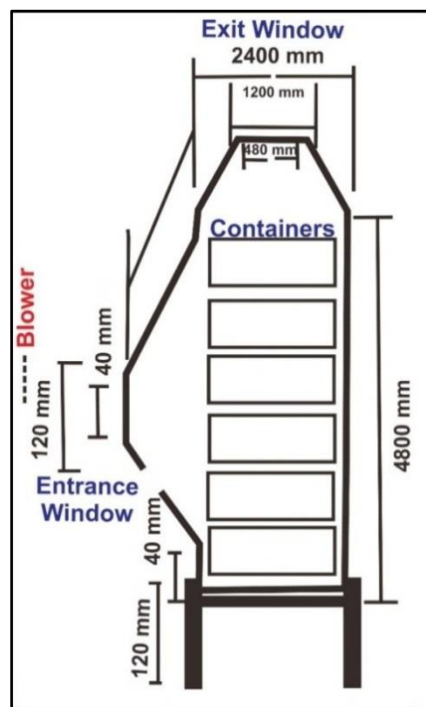


Figure 4. Modified schematic diagram of the geothermal tomato drier system from Ehiem's research[5].

Figure 4 is a design of the drying room for the tomatoes drying application system. Some data used for this design are referred to Ehiem's study. The drying room consists of 6 tomato containers. Calculation of required dryer area is determined by the amount of harvested and dried tomatoes in a day.

The hot air will flow from the blower outside to the top room. This design can produce a final moisture content of tomatoes by 26%. Heat transfer process is divided into two stages. The first stage

warms the tomatoes from the initial temperature (around 18°C) until optimum drying temperature is achieved (about 50°C). The second stage is the drying stage at constant temperature of 50°C.

6. Conclusion

Based on this study, it can be concluded that this kind of direct use is technically feasible. Drying 1 ton per day of tomatoes requires 7 kg/s of brine with brine temperature from separator of 180°C (inlet temperature) and brine temperature from HE1 should be at least 85.1°C.

The total heat required to transfer the heat from brine to water is about 741.2 kW and from water to air is about 27.9 kW. This energy transfer process is ensued by using the brazed plate heat exchanger. The heat exchanger area for heating the water is 3.14 m² and for heating the air is 3.5m².

A more detailed study by conducting economic analysis required to assess the feasibility of tomatoes drying system.

References

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