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Prototype for Making Candles and Milk Pasteurization in El Salvador (Direct Use of Geothermal)

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ABSTRACT

With the support of LaGeo, which is the electricity generating company based on geothermal energy in El Salvador, three prototypes have been built for the use of direct uses in 2017 and 2018. The first of these has been a machine for drying coffee cherries, the second a milk pasteurizer and the third a machine for making candles.

To make candles it needs paraffin, which melts at 60°C (140°F) and since we have a geothermal well that provides steam at 130°C (266°F), a prototype was built that allows the development of 30 candles.

On the other hand, it has been observed that in the surroundings of the geothermal fields of the country there are artisan milk producers, which do not follow the hygienic and safety standards. So with the heat that is available in the carrying geothermal pipes, we proceeded to make a prototype for the purpose of pasteurizing 40 bottles of fresh milk.

The coffee producers in the country place the coffee in their patios, with the purpose of reducing the humidity of the coffee cherries. This takes them up to 15 days. With the geothermal coffee dryer that use the heat of a carrying geothermal pipe, it is possible to reduce the drying period to two days.

This document summarizes and presents two of the mentioned prototypes (candles and pasteurization), part of the calculations made for the designs is shown and a brief description of each is made.

In general, many more applications can be installed in the geothermal fields, such as pasteurization of juices, obtaining essential oils for perfumes, cultivation of mushrooms, absorption refrigeration system, etc.

INTRODUCTION

The machine to make candles is composed of a heat exchanger that receives geothermal steam at 140 °C directly from the AH8 well at the Geothermal Field of Ahuachapán. This heat exchanger is double tube, so the steam is led by the external tube, while the paraffin is lodged in the inner tube.

To the paraffin several ingredients are added. After 25 minutes everything melts and is ready to pour into the molds. The paraffin melts at 60 °C, so enough heat is available to make the candles.

The design includes 30 candles in the same way, but it can make molds of different types and shapes to take advantage of the heat exchanger.

In the case of the milk pasteurizer, it has a capacity of 0.05 m^3 (approximately 40 milk bottles). The pasteurizer consists of two heat exchangers. The first is a coil that allows the exchange of heat between water as a working fluid and the geothermal fluid. The second heat exchanger allows the exchange of heat between water as a working fluid and milk.

The first heat exchanger is a copper pipe that is wound around the geothermal pipe. Inside the copper pipe, the water is conducted as a working fluid and enters, driven by a pump at 25°C. At the other outlet end, the water comes out at 80°C, since it has been heated by the transfer of heat from the geothermal pipe. The second heat exchanger is a double stainless steel tube. In the outer tube the water is conducted at 80°C, while inside the milk is housed, which is heated up to 63°C.

1. PROTOTYPE FOR MAKING CANDLES

The techniques for the elaboration of different kinds of candles can be very varied; however the process of melting and mixing the paraffin is generally the same, melting point of 60°C (140°F).

The craft production of candles consists of placing the paraffin inside a pot next to the additives, then heating everything in a kitchen (gas or electric) to melt and mix all the materials, finally pour the mixture into a mold with the shape that want.

There are many varieties of candles; some of them are shown in Figure 1. Types of candles [Google].



Figure 1. Types of candles [Google]

1.1 Amount of energy to make candles

The selected type of candle has a diameter of 8 cm (3.15 inches) and a length of 9.5 cm (3.74 inches), as shown in Figure 2. Dimensions of candles [Google].

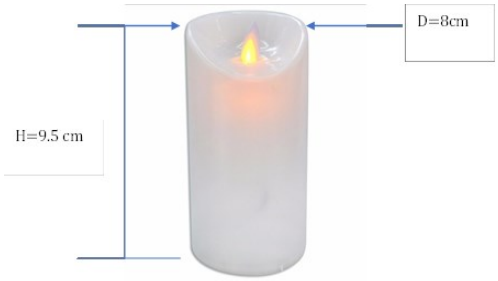

Figure 2. Dimensions of candles [Google]

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The volume of each candle is calculated of 477.52 cm^3. Considering that 30 candles will be obtained, the volume of candles per lot is 14,325.66 cm^3.

The paraffin mass to be used (considering a liquid paraffin density value, obtained by experimentation, such as 750 kg/m^3) is calculated by:

$$m_{par} = \rho_{par} \times Volume \quad (1)$$

Where:

m_{par} = Paraffin mass (kg)

ρ_{par} = Paraffin density (kg/m^3)

$Volume$ = Volume of 30 candles (m^3)

$$m_{par} = 750\frac{kg}{m^3} \times 14{,}325.66\ cm^3 \times \frac{1\ m^3}{1x10^6 \times cm^3}$$

$$m_{par} = 10.74\ kg \cong 11\ kg$$

Known paraffin mass to melt 11 kg (24.25 pounds), it proceeds to calculate the amount of energy that should be supplied to the paraffin.

It is assumed that the paraffin will start from a temperature of 25°C (77°F) and that it will be increased to a temperature of 120°C (248°F). The temperature of 120°C (248°F) is chosen as the goal by recommendation of a local candle producer, who expresses that this temperature is ideal to achieve a correct state of mixing of all the elements that will make up the finished candle and melts the paraffin in less time possible.

As the process involves a phase change, the energy must be separated into 3 stages, since it is not possible to carry the paraffin from 25°C (77°F) to 120°C (248°F) without necessarily passing through a phase change from solid to liquid.

The energy that must be supplied to the paraffin consists of three stages:

- Sensitive heat (obtained on the internet) Cp_par=2.95 kJ/kg K, to carry the paraffin from 25°C (77°F) to its melting point 60°C (140°F).

- A latent heat (obtained on the internet) L_par=244 kJ/kg, necessary to melt all the paraffin.
- Another sensible heat, to carry the paraffin completely melted from 60°C (140°F) to 120°C (248°F), however it is estimated equal to the value of Cp_par=2.95 kJ/kg K

The energy needed to melt and heat the paraffin is obtained from the energy balance of the equation:

$$E_{par} = Q_{sensible1} + Q_{latent} + Q_{sensible2} \quad (2)$$

Where:

E_{par} = Energy to melt paraffin (kJ)

$Q_{sensible1}$ = Sensible heat (kJ)

Q_{latent} = Latent heat (kJ)

$Q_{sensible2}$ = Sensible heat (kJ)

$$Q_{sensible1} = m_{par} \times Cp_{par}\ (60 - 25°C) \quad (3)$$

Where:

$Q_{sensible1}$ = Sensible heat (kJ)

m_{par} = Paraffin mass (kg)

Cp_{par} = Specific heat (kJ/kg K)

$$Q_{sensible1} = 11\ kg\ \times 2.95\ {}^{kJ}/_{kg°C} \times\ (60 - 25)°C$$

$$Q_{sensible1} = 1{,}135.75\ kJ$$

$$Q_{latent} = m_{par} \times L_{par} \quad (4)$$

Where:

Q_{latent} = Latent heat (kJ)

m_{par} = Paraffin mass (kg)

L_{par} = Latent heat value (kJ/kg)

$$Q_{latent} = 11\ kg \times 244\ {}^{kJ}/_{kg}$$

$$Q_{latent} = 2{,}684.0\ kJ$$

$$Q_{sensible2} = m_{par} \times Cp_{par}\ (120 - 60)°C \quad (5)$$

Where:

$Q_{sensible2}$ = Sensible heat (kJ)

m_{par} = Paraffin mass (kg)

Cp_{par} = Specific heat (kJ/kg K)

$$Q_{sensible2} = 11\ kg\ \times 2.95\ {}^{kJ}/_{kg°C} \times\ (120 - 60)°C$$

$$Q_{sensible2} = 1{,}947.0\ kJ$$

$$E_{par} = 1{,}135.75\ kJ + 2{,}684.0\ kJ + 1{,}947.0\ kJ$$

$$E_{par} = 5{,}766.75\ kJ$$

The quantity of calculated energy is necessary to obtain the time to melt the paraffin. By calculations is determined in 35 minutes.

1.2 Design of the heat exchanger (double tube)

The best alternative that was selected is a double tube. The external tube hast a tangent entry to the steam and other tangent exit that permit the return of the steam, as shown in Figure 3. Heat exchanger – double tube.

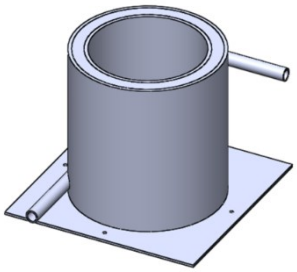

Figure 3. Heat exchanger – double tube

The heat exchanger was built from two tubes of steel geothermal pipe. They are of nominal card of 16 and 12 inches. The length of the tubes is 400 mm (15.74 inches). The diameter of the outer tube is 406.35 mm (16 inches) and the inside is 323.85 mm (12.75 inches). The steam is conducted in the space between both tubes.

The geothermal well AH-8 at the Ahuachapán Geothermal Field (which is not used for the electricity production operation) is used as a heat source, and it has steam at 140°C (284°F).

Through measurements made at the site, the steam temperature at the inlet and outlet of the exchanger are known. The steam enters the heat exchanger at 130°C (266°F) and exits at 110°C (230°F).

In the Figure 4. Candle production system. [Own design], the geothermal well is shown as the heat source, the heat exchanger, the steam pipeline and the ball valves that restrict the passage of steam.

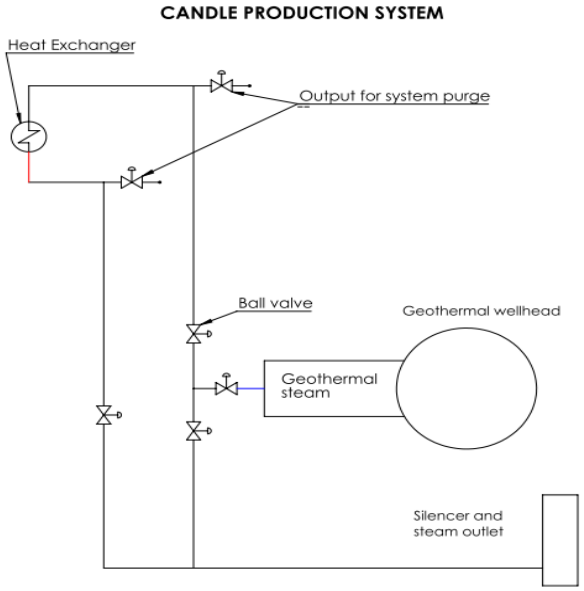

Figure 4. Candle production system. [Own design]

1.3 Candles

With this system it can make up to 30 candles with the following ingredients:

Table 1. Ingredients of candles

Description	Quantity	Unit
Paraffin	11,200	Grams
Vybar	180	Grams
Flavoring	180	Grams
Colorant	Depend of the user	

The vybar is un additive to make candles. It helps to desmounting candles from the molds.

The production of 30 candles, it starts by melting the paraffin in the heat exchanger, waiting for the geothermal steam to transfer heat to the heat exchanger. After 30 minutes it has all the ingredients in liquid state, pour them into the molds and then wait for them to solidify (Figure 5. Process).

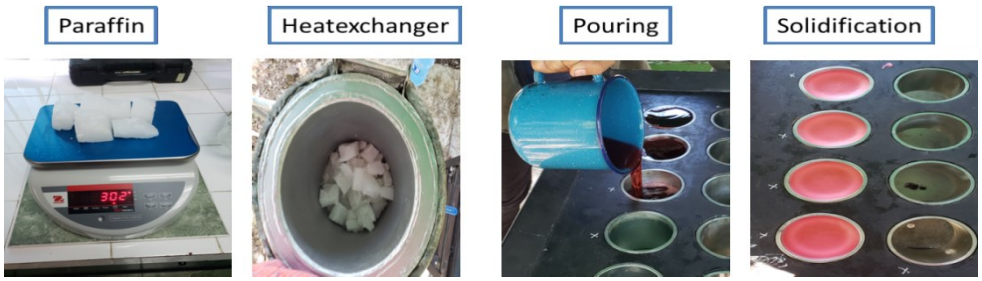

Figure 5. Process

1.4 Tests

Several tests were performed to evaluate the functioning of the system. The process takes 30 minutes (Table 2. Data test. [Experimental calculations]). The time is enough to melt the paraffin and all the necessary ingredients. In addition, in that same time the colorant and the flavoring is incorporated.

Table 2. Data test. [Experimental calculations]

Hour	T. in of steam °C	T. Heatexchanger °C	T. out of steam °C
9:50	117	111	104.5
9:55	121	116.3	118
10:04	117.6	118.4	115.1
10:10	119.5	124.4	119
10:15	130.2	124.4	122
10:20	128.8	124.9	122.3

The variation of the steam temperature (Figure 6. Variation of temperature) shows when entering the exchanger (blue color) and the variation of the steam temperature at the heat exchanger outlet (red color).

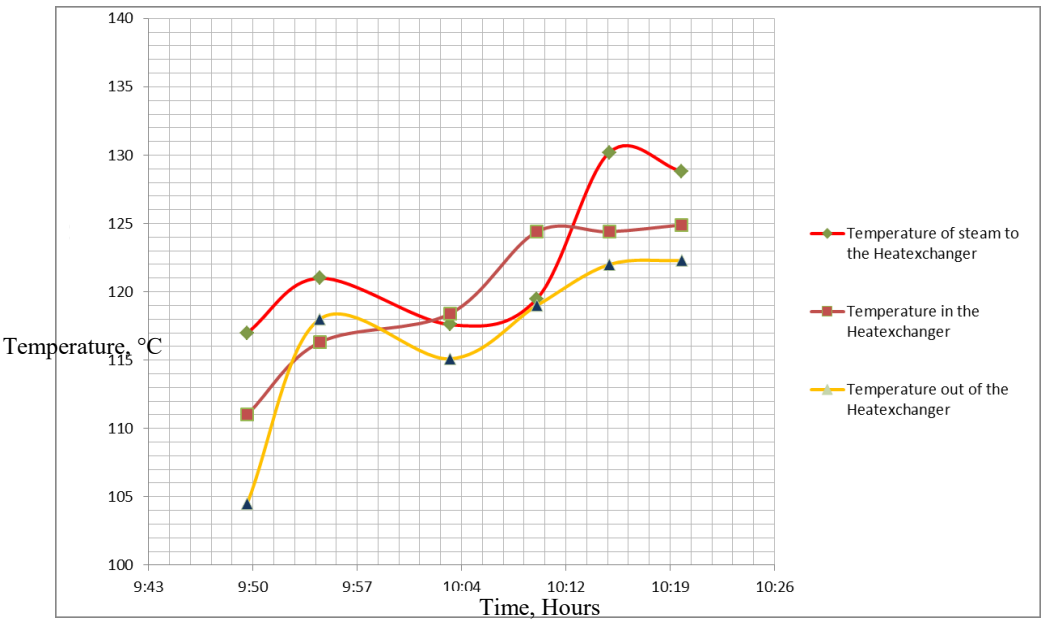

Figure 6. Variation of temperature

When the paraffin heating process has finished, pour it into the molds with the shape of the candle (Figure 7. Solidification candles), to wait for the cooling and solidification of the candle. The cooling and solidification time takes 4 hours.



Figure 7. Solidification candles

2. PROTOTYPE FOR MILK PASTEURIZATION

The municipalities and surrounding communities at the Geothermal Fields in El Salvador are characterized by agricultural and cattle areas, which dedicate their activities to the cultivation and raising of animals. In the particular case of milk, this is obtained from cows without considering good hygiene practices and lack of safety, so these communities are exposed to diseases that can be caused by poor handling of milk.

The families of these communities who own cattle and obtain products such as milk, cheese and cream often have a high microbial content, which is processed and sold to consumers. So the implementation of a pasteurization system (direct use), can help in the reduction of diseases of milk and its derivatives.

2.1 Pasteurization

Milk pasteurization is a special type of heat treatment that is defined as "any heat treatment of milk that ensures the destruction of tuberculosis bacillus without significantly affecting the physical and chemical properties of milk." The most resistant organism is the tuberculosis bacillus, which can be destroyed by heating the milk at 63°C (145.4°F) for 30 minutes.

The tuberculosis bacillus is considered the reference organism in pasteurization. Any heat treatment that destroys tuberculosis bacillus it is supposed to destroy other milk pathogens (Figure 8. Pasteurization).

The phosphatase test is a test used to check that milk has been properly pasteurized. The test result must be negative; there must be no detectable phosphatase activity.

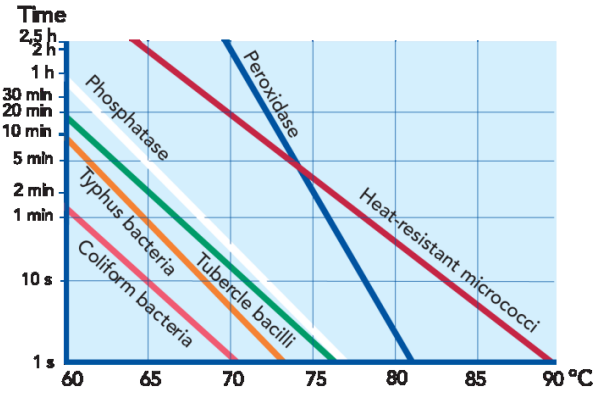

Figure 8. Pasteurization

The Figure 9. Pasteurization methods, shows the time considered to pasteurize milk. The method of 63°C (145.4°F) for 30 minutes has been considered.

Pasteurization Temperature vs. Time	
Vat (Batch) Pasteurization	
Temperature	**Time**
63°C (145°F)*	30 minutes
HTST Pasteurization	
Temperature	**Time**
72°C (161°F)*	15 seconds
89°C (191°F)	1.0 second
90°C (194°F)	0.5 seconds
94°C (201°F)	0.1 seconds
96°C (204°F)	0.05 seconds
100°C (212°F)	0.01 seconds

Figure 9. Pasteurization methods

2.2 System for geothermal pasteurization

The system for pasteurizing (Figure 10. Pasteurization machine) uses a pumping system to circulate the working fluid throughout the prototype, in which it is first started by a water pump, this pump sucks water from a storage tank, and then it is pumped to the coil tube heat exchanger that is installed in the geothermal fluid reinjection pipe. With this, the water temperature is increased from 20°C (68°F) to 80°C (176°F).

The water continues to a second heat exchanger, consisting of two tubes. The milk is placed in the inner tube. The water that comes from the coil tube, transfers heat to the milk, causing the temperature of the milk to go from 25°C (77°F) to 63°C (145°F). The last temperature is the pasteurization temperature and should be maintained for 30 minutes.

Once the water leaves the external tube of the second heat exchanger, it goes to the storage tank where it will be sucked again by the water pump.

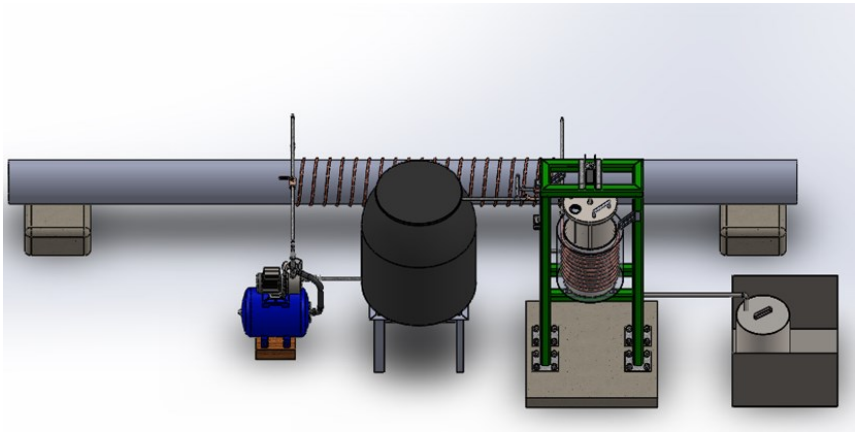

Figure 10. Pasteurization machine

2.3 Determining the energy to pasteurize

The temperature for pasteurization is considered at 63°C (145.4°F). The temperature of the milk starts at 25°C (77°F).

Considering:

- density of 1,032 kg/m^3 and specific heat of 3.89 kJ/ kg-K for milk
- A volume of 0.05 m^3 for milk
- density of 7,900 kg/m^3 and specific heat of 0.477 kJ/ kg-K for stainless steel
- A cylindrical container of 2.225x10^{-3} m^3 for stainless steel

The energy required to perform the heating considering the entire system isolated is Eo.

$$Eo = m\rho C\Delta T\ milk + m\rho C\Delta T\ stainless \tag{6}$$

Where:

Eo = Energy to pasteurize (kJ)

m = Volume of milk (m^3)

ρ = Density (kg/m^3)

C = Specific heat (kJ/kg K)

ΔT = Delta of temperature

$$Eo = 0.05m^3 \times 1{,}032\ {}^{kg}/_{m^3} \times 3.89\ {}^{kJ}/_{kg\,°C} \times (63-25)°C + 2.225 \times 10^{-3}m^3 \times 7{,}900\ {}^{kg}/_{m^3} \times 0.477\ {}^{kJ}/_{kg\,°C} \times (63-25)°C$$

$$Eo = 7{,}946.12\ kJ$$

2.4 Design of heat exchanger for water (coil tubing)

The temperature at which the water (working fluid) enters the coil tube is 20°C (68°F) (enthalpy of 83.915 kJ/kg) and is expected to come out at 80°C (176°F) (enthalpy of 335.02 kJ/kg). Mass flow of water is estimated of 0.0608 kg/s (experimental calculations). Figure 11. Coil tube shows the coil tube rolled on the geothermal pipe that conducts the geothermal fluid (well TR12, Geothermal Field of Berlin).

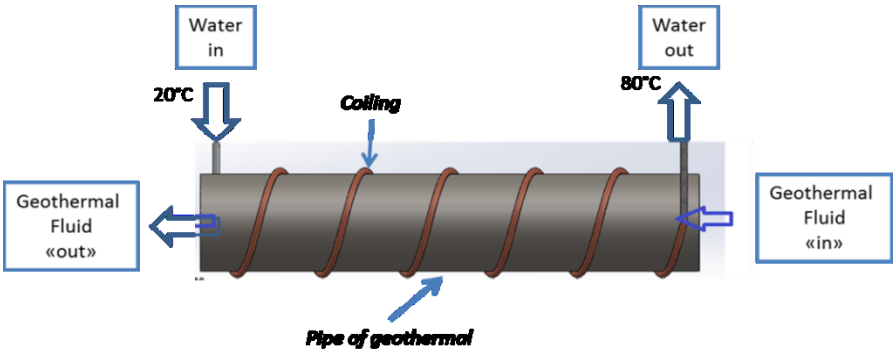

Figure 11. Coil tube

The coil tube where the water is conducted is copper, with an external diameter of 0.158 m (0.625 inches) and one internal diameter of 0.138 m (0.545 inches).

The conduction pipe of the geothermal fluid is made of steel A-53 grade B. It has an external diameter of 0.30476 m (11.99 inches) and an internal diameter of 0.3238 m (12.74 inches).

The total conduction coefficient U is obtained by calculations and is 1,913.13 W/m^2°C. The logarithmic average temperature is obtained by calculations and is 133.24°C.

The heat flows for the water at the inlet of the coil is obtained by the following equation.

$$Q_{water} = m_{water} \times (h_{out} - h_{in}) \tag{7}$$

Where:

Q_{water} = Heat for water (kJ/s)

m_{water} = Mass flow of water (kg/s)

h_{out} = Enthalpy of water at 80°C (kJ/kg)

h_{in} = Enthalpy of water at 20°C (kJ/kg)

$$Q_{water} = 0.0608\ {}^{kg}/_{s} \times (335.02 - 83.915)\ {}^{kJ}/_{kg}$$

$$Q_{water} = 15.26\ {}^{kJ}/_{s} = 15.26\ kW$$

The length of the copper pipe that is rolled as a coil tube around the geothermal pipe

$$Q_{water} = 0.02\,\pi \times D \times L \times U \times \Delta T \tag{8}$$

Where:

Q_{water} = Heat for water (kJ/s)

D = External diameter of copper pipe (m)

L = Length of the copper pipe (m)

U = Conduction coefficient (W/m²°C)

ΔT = Logarithmic average temperature (°C)

A factor of 0.02 representing that only 2% of the copper tube will be in contact with the geothermal water transport pipe, this value has been assumed due to the geometrical configuration of the heat exchanger.

Clearing L of the equation.

$$L = \frac{Q_{water}}{0.02\pi \times D \times U \times \Delta T}$$

$$L = \frac{15.26\ kW}{0.02\pi \times 0.0158\ m \times 1{,}913.13\ {}^{W}/_{m^2°C} \times 133.24\ °C}$$

$$L = 60.30\ m$$

The number of turns that must be rolled around the geothermal pipe is obtained by dividing the length of the copper pipe divided by the outer diameter of the geothemal pipe.

$$N = \frac{L}{\pi \times Dext} \tag{9}$$

Where:

N = Turns

L = Length of the copper pipe (m)

$Dext$ = External diameter of the geothermal pipe (m)

$$N = \frac{60.30\ m}{\pi \times 0.3238\ m}$$

$$N = 59.28\ turns$$

The reduction of temperature of the geothermal fluid is calculated as:

Considering the geothermal fluid in at 183°C (776.33 kJ/kg as water) and mass flow of the geothermal fluid in the reinjection pipe of 57.4 kg/s.

$$h_{gout} = \frac{(m_g \times h_{gin}) - Q_{water}}{m_g} \tag{10}$$

Where:

h_{gout} = Enthalpy of geothermal fluid out (kJ/kg)

h_{gin} = Enthalpy of geothermal fluid in at 183°C

m_g = Mass flow of geothermal fluid (kg/s)

Q_{water} = Heat for water (kJ/s)

$$h_{gout} = \frac{(57.4\,{}^{kg}/_{s} \times 776.33\,{}^{kJ}/_{kg}) - 15.26\,{}^{kJ}/_{s}}{57.4\,{}^{kg}/_{s}}$$

$$h_{gout} = 776.06\,{}^{kJ}/_{kg}$$

Extrapolating with steam tables, the temperature of the geothermal fluid at the outlet is 182.93°C, therefore the reduction of temperature is not significant.

2.5 Double tube heat exchanger for milk

From different discussions it was decided to build a double tube heat exchanger. This serves to house the milk inside. They are two stainless steel tubes. In the inner one the milk is lodged and in the external the water passes (working fluid).

The temperature of the entering water is estimated at 80°C (176°F). From different calculations it was established that the water temperature at the exit is 63°C (145.4°F).

The Figure 12. Heatexchanger of double tube, shows the shape of the double-tube heat exchanger, with the purpose of pasteurizing the milk (which is inside).

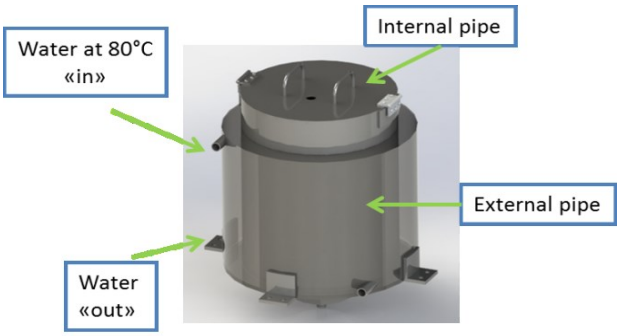

Figure 12. Heatexchanger of double tube

The mass flow of water at 80°C (176°F) is considered at 0.0608 kg/s ((experimental calculations). The external diameter of the inner tube is 0.404 m (15.90 inches), while the external diameter of the external tube is 0.504 m (19.84 inches). The height of the heat exchanger is 0.40 m (15.74 inches).

The milk is lodged in the inner tube at 25°C (77°F) and heated to 63°C (145.4 or 149°F).

Calculating the logarithmic average temperature to counterflow is 33.75°C.

By calculation is obtained the total heat transfer coefficient U=472.72 W/m^2 °C

The heat flows that occurs from the hot water circulating inside the jacket and milk is calculated with the following equation.

$$Q = \pi \times D_{extmilk} \times L_h \times U_h \times \Delta T_{milk} \quad (11)$$

Where:

Q = Heat for milk (kW)

$D_{extmilk}$ = External diameter of heatexchanger (m)

L_h = Height of heatexchanger (m)

U_h = Total conduction coefficient (W/m^2 °C)

ΔT_{milk} = Logarithmic average temperature

$$Q = \pi \times 0.404\,m \times 0.4\,m \times 472.72\,{}^{W}/_{m^2{}^{\circ}C} \times 33.75{}^{\circ}C$$

$$Q = 8{,}099.50\,W = 8.099\,kW$$

Now we proceed to determine the time to raise the temperature of the milk 25°C to the pasteurization temperature at 63ºC.

$$t = \frac{Eo}{Q} \tag{12}$$

Where:

t = Time to pasteurize (min)

Eo = Energy to pasteurize (kJ)

Q = Heat for milk (kW)

$$t = \frac{7{,}946.12\ kJ}{8.099\ kW} = \frac{7{,}946.12\ kJ}{8.099\ kJ/s}$$

$$t = \ 981.12\ s = 16.35\ min$$

The Figure 13. Sequence, shows a sequence from obtaining freshly milk, placing the milk in the double-tube heat exchanger, waiting for 30 minutes to warm up and finally packing it to be used in subsequent processes such as making cheeses or creams.



Figure 13. Sequence

2.6 Tests

Forty milk bottles (30 liters) were placed in the double-tube heat exchanger to perform several tests.

Freshly milk was placed in the heat exchanger at 31°C (87.8°F). On the other hand, the water (working fluid) was at 30°C (86°F). Once the pump is turned on, it can be seen that the water temperature begins to increase.

Upon reaching the first 5 minutes, the water temperature is 50°C (122°F).

The pasteurization temperature, which is 63°C (145.4°F), was reached after 30 minutes of operation.

The milk was kept for another 30 minutes at 65°C (149°F) to meet the time required to pasteurize the milk. After that, a sample is stored and sent to a laboratory for the phosphatase test that help confirm that the milk has been pasteurized.

The Figure 14. Curve of pasteurization, shows the behavior of the water temperature (working fluid) as well as the temperature of the milk.

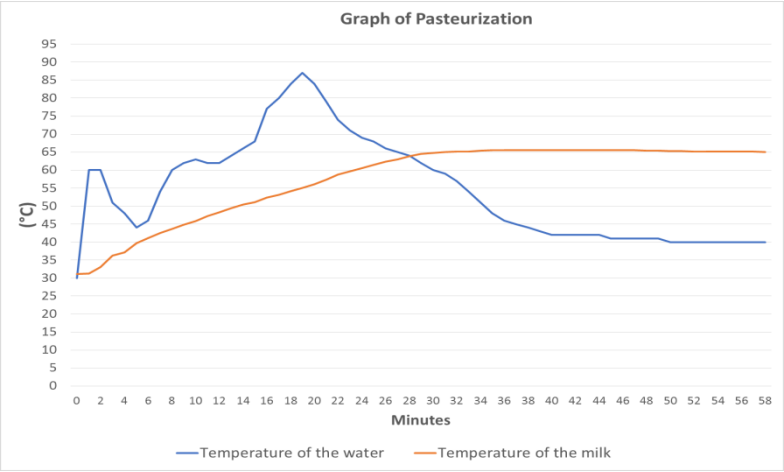

Figure 14. Curve of pasteurization

The Figure 15. Prototype of milk pasteurization, shows the prototype of pasteurizer and the pasteurized milk in bottles.



Figure 15. Prototype of milk pasteurization

3. CONCLUSION

The candle making machine can be built in any geothermal field and put at the service of local communities for their own benefit. The operator of the geothermal field can decide whether to sell the steam or give it for free so that people from the local communities can serve it for the commercialization of candles.

The milk pasteurization prototype can also be put at the service of the communities around the geothermal plant. But it can also expand its installed capacity and include the production of cheeses and creams in collaboration with the country's dairy industry.

The heat that it has in the geothermal fields can be seen in geothermal wells, geothermal pipes and fumaroles and in all of them it can install projects that take advantage of this heat.

The applications of direct uses can be very varied and it is necessary to make the knowledge of its advantages to agricultural producers and local industries.

Funding is needed to develop more projects that are useful for the agricultural sector or medium-sized companies.

For temperature ranges between 60°C and 90°C, it is feasible to install heat exchangers that allow the use of heat in specific processes.

4. ACKNOWLEDGEMENTS

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REFERENCES

Yunus A. Cengel, Afshin J. Ghajar: Fundamentals and Applications of Heat and Mass Transfer (2011).