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Geothermal Energy System for Honey Extraction Process

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Abstract
In the age of renewable energy, geothermal energy is playing a pivotal role in society. This resource can be utilized either directly or indirectly. Some of the common direct application areas of this resource include agriculture, aquaculture, and balneology, among others. Honey processing has emerged as a critical area where geothermal energy can be applied for societal benefits. This study sought to determine how geothermal energy can be used in honey extraction process. The inspiration came from the honey extraction challenges faced by the bee farmers in Menengai area in Kenya, which leads to wastage and poor quality. The designed system uses geothermal energy and its deployment in honey extraction processing would help to reduce wastage. The simulation of specific flow rates of the geothermal water (fluid) and air flow across the heat exchanger indicated that the desired temperature at which honey is extracted from honeycombs can be achieved. Similarly, fine-tuning the parameters realised the temperatures for the preservation of the extracted honey via denaturing of yeast. This system will help to improve honey extraction process and promote large scale honey production.

Keywords: *Geothermal Energy, HMF, Honey Processing, Lindal diagram, Simulink,*

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I. Introduction

Accessibility to reliable, affordable, and clean energy is necessary for the attainment of improved standards of living across the world. According to Boon and Kankam (2009), shifting to reliable energy production, and the way the energy is utilized is of great importance. Besides being a clean form of energy, geothermal energy is also sustainable since it is generated from the earth (Johnston *et al.*, 2011). This energy has been used for ages dating back to early 1900. The first application of geothermal energy dates back to Italy between 1904 and 1905, where it was used for the production of power with the experimental projects of Prince Gionori Conte. Since then, geothermal technology started spreading gradually to other countries. Currently, the resource is utilized in many countries in different parts of the world. Different applications of geothermal energy depend on the chemical composition and thermodynamic properties of the resource. The major applications include aquaculture, spas, and pools, greenhouses heating, milk pasteurization, food drying, timber drying, among other uses.

An emerging area where geothermal heat is applied is honey production. Over the years, honey producers have been faced with challenges in honey extraction processing. The common problem faced by the honey producers over time is the loss in honey quality and wastage due to overreliance on poor honey processing methods (Musinguzi, Bosselmann, & Pouliot, 2018). In the quest for improvement in honey quality and reduction in honey losses during extraction processing, geothermal energy has been identified as a potential alternative since it allows for regulation of temperatures during honey processing (Radtke & Lichtenberg-Kraag, 2018). In this regard, there have been efforts to design an efficient system that utilizes geothermal energy for honey processing. The system will help to promote honey production activities in the Menengai area, Nakuru, a city in Kenya with a high geothermal potential.

II. Literature Review

Geothermal Energy Applications

Geothermal technology has gained tremendous growth in the recent past. Geothermal energy is clean and renewable energy, which can be used either to generate electricity or for direct applications and has a high potential for growth. According to Shere (2010), within 10,000 meters in the earth's surface, the amount of heat is approximated to be about 50,000 times the heat contained in gas and oil. Therefore, it implies that geothermal energy has a huge potential to offer a significant solution to the energy crisis in the future.

As of 2010, geothermal technology was popular in over 79 countries globally, with the leading users being the USA, Norway, Iceland, China, Japan, Turkey, Germany, and France (Wang *et al*., 2018). By 2016, the total installed capacity of geothermal energy stood at approximately 901 megawatts (MW) globally. With the increasing momentum for the search for sustainable energy sources, a large number of countries have gaining interest in the development of geothermal energy. This growing popularity of geothermal power is partly due to the increasing cost of electricity, which creates the need for alternative sources of energy.

Geothermal energy is naturally regenerated. Therefore, this energy is not affected by global resource depletion or the increasing costs of fossil fuels. Geothermal energy is also not dependent on weather, and consequently, it can contribute a lot to the global energy transformation. The utilization of geothermal energy has gained high popularity, and in 2017, about 25 nations across the world had geothermal power plants in operation with a total installed capacity of 13 Gigawatts Electric (GWe) (IRENA, 2014). If the full potential of geothermal energy is realized, it would have numerous benefits both at local and international levels.

The use of geothermal resources depends on their enthalpy and temperature. According to Kiruja (2011), based on the thermodynamic properties, geothermal resources can be grouped as high, medium, and high enthalpy. High enthalpy geothermal fluid is used to generate electricity, while low and medium enthalpy geothermal fluids are used directly in various ways. Currently, geothermal energy has found direct use in multiple applications such as drying agricultural produce, air conditioning, and fish farming, among others. Therefore, this resource has the potential to present a solution to the challenge of regulating temperatures faced by beekeepers during the processing of honey. This can be achieved through a system that utilizes geothermal water. The use of geothermal water helps in heating the honey under controlled temperatures. The heating helps to lower the moisture content and to destroy all the yeast present in the honey (Sircar & Yadav, 2016).

Honey Extraction Methods employed by Menengai Farmers

There are various methods of extracting and processing honey that are commonly used by bee farmers. The methods include straining, water bath, bulk processing, and centrifugal method (Njagi Christopher, 2016). Often, Menengai farmers utilize traditional methods, which include locally available materials. From the analysis of the data gathered using questionnaires, many farmers in the Menengai forest area use the water bath method to process honey. The farmers collect honey from honeycombs, which are made by bees inside the wooden hives. During honey harvesting, the honeycombs are removed from the hive, and honey is extracted by first heating it in a water bath.The heating is done to facilitate both straining and fast handling and to destroy yeast that may be present to reduce the chances of fermentation.

Another method commonly used by farmers to process honey is mashing and squeezing honey on clothes. In this method, the bee farmer’s mash and press honeycombs to extract honey. These machines use human power making them less efficient (Kaitano, 2016). The traditional methods of beekeeping accompanied by traditional methods of extracting and processing honey have been responsible for the low production of honey in terms of volume and generated income. According to Kaitano (2016), insufficient knowledge on modern farming methods in Menengai area negatively affects the direct use of geothermal energy.

III. Methodology

The purpose of the study was to come up with a way of harnessing and utilizing the geothermal water in honey processing. This energy can be harnessed to present a suitable means of honey extraction processing under controlled conditions. The methodology involved designing a system that utilizes geothermal energy in honey extraction and processing to minimize wastage. Derivation of heat transfer equations was performed when the order was assumed to be in operation with steady-state heat flow and derived from heat energy equations. An air convection flow equation was derived. Mathematical modelling and simulations were done using MATLAB and Simulink.

IV. Analysis and Results

System Design

The system was designed to minimize wastage during honey extraction and regulate the temperature to ensure that the extracted honey is of good quality. The geothermal fluid flows into heat exchange, and the air is blown by the blower inside the heat exchanger for heat to be extracted from the geothermal fluid to the honey extraction chamber, as shown in Figure 1. The hot air from the heat exchanger was designed to pass through the extraction chamber packed with honeycombs. The speed of the blower is governed by the temperature at which honey is to be extracted. The temperature sensor regulates the speed of the motor to suit the required air velocity in the heat exchanger.

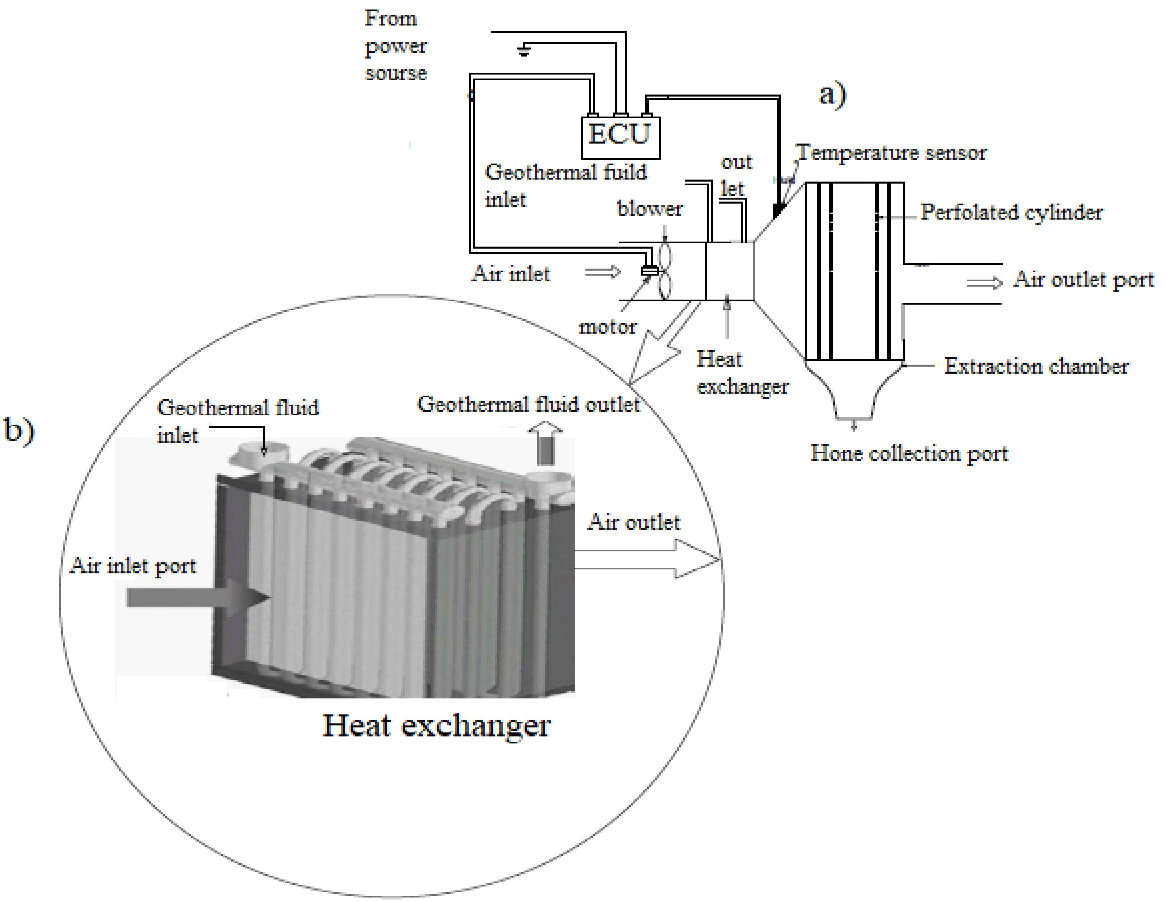

Figure 1: Cross section block diagram (a) of the geothermal honey extraction system and (b) the 3D of the heat exchanger system

Section 1: Heat Energy Equations

The system was modelled as one-dimensional radial heat flow. From Figure 2 (Adopted and modified from Incropera, 2005) and assuming the system does not generate any energy, the heat transfer equation in the system given by:

$$\frac{1}{r}\frac{d}{dr}\left[kr\frac{dT}{dr}\right] = 0 \qquad \text{(i)}$$

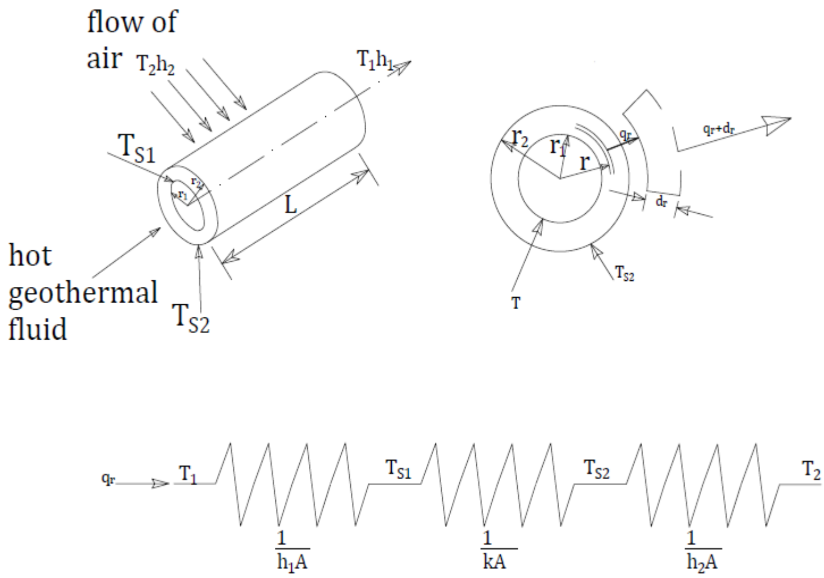

Figure 2: Heat transfer across the heat exchanger pipes

Form Fourier's Law, for solid cylindrical surface heat flow rate by conduction, the heat flow rate is expressed as:

$$q_r = -\left[kA\frac{dT}{dr}\right] = -k(2\pi rl)\frac{dT}{dr} \qquad \text{(ii)}$$

Where:

a) $\mathbf{A = 2\pi r}\ \boldsymbol{L}$ = area of the surface normal to the direction of heat transfer.

b) $\mathbf{q_r}$ = Rate of heat transfer, where heat transfer flux q_r", is a constant value in the radial direction.

Integrating equation (i) twice gives a general solution (iii) below.

$$\iint_{Tr1}^{Tr2} \frac{1}{r}\frac{d}{dr}\left[kr\frac{dT}{dr}\right] = \iint 0dT$$

$$T(r) = C_1 \ln r + C_2 \qquad \text{(iii)}$$

For boundary conditions: $T_{r1} = T_{s1}$ and $T_{r2} = T_{s2}$ (Figure 3), C_1 and C_2 can be obtained by applying this condition to the general solution to obtain:

$$T_{s1} = C_1\, lnr_1 + C_2$$

And $$T_{s2} = C_1\, lnr_2 + C_2$$

$$C_1 = \frac{T_{s1} - T_{s2}}{ln(^{r_1}/_{r_2})} \text{ and } C_2 = T_{s2} - \left\{\frac{T_{s1} - T_{s2}}{ln(^{r_1}/_{r_2})}\right\} lnr_2$$

Substituting C_1 and C_2 to equation (iii) temperature for the system is as follows:

$$T_r = \frac{T_{s1} - T_{s2}}{ln(^{r_1}/_{r_2})}\, ln\frac{r}{r_2} + T_{s2} \qquad \text{(iv)}$$

Due to the distribution of temperature for a system linked to radial conduction the transfer of heat through a cylindrical surface is in the logarithmic form and not in linear form such as on a flat wall of comparable condition. When equation 4.4 is substituted into equation 4.2 a general heat rate equation is obtained as follows Where

$$q_r = \frac{2\pi lk\,(T_{s1} - T_{s2})}{ln(^{r_2}/_{r_1})} \qquad \text{(v)}$$

$$R_{t\ (cond)} = \frac{ln(^{r_2}/_{r_1})}{2\pi lk}$$ This is called thermal resistance.

The heat flow into the open air from the centre of the tube occurs in convection form. For the whole system from T_1 -> T_{s1} -> T_{s2} -> T_2, the rate of heat flow equation (v) can be formulated as:

$$q_r = \frac{T_{a1} - T_{a2}}{\frac{1}{2\pi r_1 l h_1} + \frac{ln\left({r_2}/{r_1}\right)}{2\pi lk} + \frac{1}{2\pi r_2 l h_2}} \qquad \text{(vi)}$$

Where:
q = heat transfer rate (W)
r = pipe radius (M)
L = pipe length (M)
T = temperature (k) or (c)
K = thermal conductivity (W/m.k)
H=convection heat transfer coefficient (W/m^{2}K)
Those three equations (vi.a, vi.b, and vi.c) can be used to calculate T_{s1} and T_{s2} because qr = q_{r1} = q_{r2} = q_{r3}.

Section II: Air Convection Flow Equations

A flow of air convection via a bank of tubes is modelled mathematically as heat exits the outer side of the pipes (Figure 3). The rows of the heat exchanger (HE) tube are staggered in the same direction as the velocity of the fluid, which is characterized by the diameter of the tube and by the transverse and longitudinal pitch measured between the centres of the tube. Boundary layer separation effects and wake interactions dominate the bank. This, in turn, influences convection heat transfer. The average convention coefficient of the heat transfer (h) can be tabulated using the equation given below.

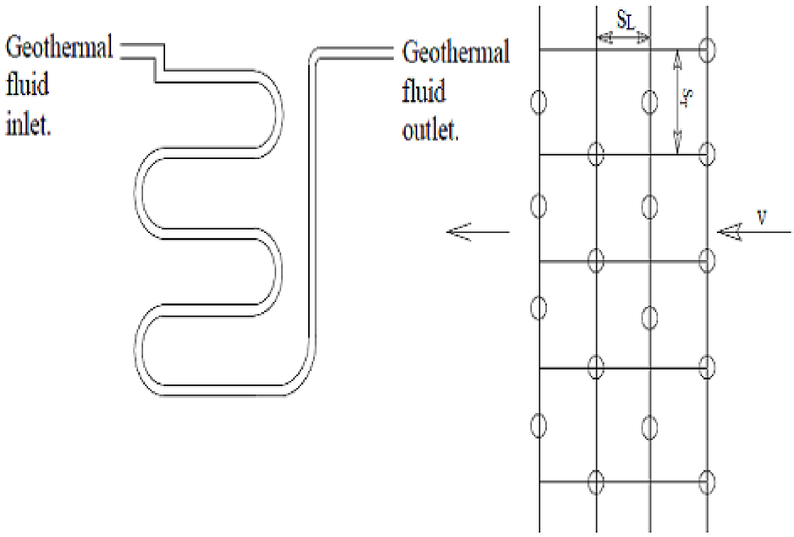

Figure 3: Heat exchanger pipes layout (Adopted and modified from Incropera, 2005)

Zhukauskas Model 1972 proposed a correlation of the form:

$$\bar{N}_{UD} = CRe_{D,max}^{m} Pr^{0.36}\left(\frac{Pr}{Pr_s}\right)^{1/4} \qquad \text{(vii)}$$

Where

$$Re_{D,max} = \frac{v_{max} D}{v} \qquad \text{(viii)}$$

V = kinematics viscosity of air (m^2/s)
P_r = Prandtl number
The Reynolds number (Re D,max) for the foregoing correlations was dependent on the maximum velocity of the fluid (Vmax) that occurs within the tube bank. For the staggered configuration, the occurrence of the maximum velocity may be at either the diagonal or the transverse planes whenever the rows are placed as described below:

$$S_D = \{S_L^2 + (S_T/2)^2\}^{1/2} > {(S_T + D)}/{2}, then \qquad \text{(ix)}$$

$$v_{max} = \frac{S_T}{S_T - D} V \qquad \text{(ix)}$$

Then

$$v_{max} = \frac{s_T}{2(S_D - D)} V \qquad \text{(ix)}$$

The coefficient (h) heat transfer can be calculated by the following equation

$$\bar{h} = \bar{N}_{UD} \frac{K}{D} \qquad \text{(x)}$$

Where

K = gas (air) thermal conductivity (W/m.k).

The log-mean temperature difference is used to calculate heated air temperature produced from the heat exchanger.

$$\Delta T_{lm} = \frac{(T_{S_2} - T_i) - (T_{S_2} - T_{o_1})}{ln\left(\frac{T_{S_2} - T_i}{T_{S_2} - T_{o_1}}\right)} \qquad \text{(xi)}$$

For which

T_i = temperatures of the fluid as it enters.

T_{o1} = temperatures of the fluid as it leaves.

T_{s2} = the tube outside surface temperature.

Note: The outlet temperature T_o, which is needed to determine ΔT_{lm}, may be estimated from the equation

$$\frac{T_{S_2} - T_{o_1}}{T_{S_2} - T_i} = exp\left(-\frac{\pi D N \bar{h}}{\rho V N_T S_T C_P}\right) \qquad \text{(xii)}$$

For:

N = Total number of tubes in the bank.

N_T = number of tubes in the transverse plane.

$\boldsymbol{\rho}$ = air mass density (Kg/m^3).

C_p = gas (air) specific heat constant pressure (J/Kg.K).

Rate of heat transfer per unit length of the tubes is calculated by the following equation:

$$q' = N(\bar{h}\pi D \Delta T_{lm}) \qquad \text{(xii)}$$

And

q' =heat transfer rate per unit length (KW/m)

Design System Parameters

Table 1 below outlines the various parameters that were used in the simulation studies for the designed honey extraction system.

Table 1: The parameters used in the simulation for the design system

PARAMETER	ABRAVIATION	UNIT
Geothermal fluid heat convection coefficient	h_1	5000 W/m^{2}K
Heat exchanger pipe thermal conductivity	k	10 W/mK
Air heat convection coefficient	h_2	15 W/m^{2}K
Geothermal fluid temperature	T_{a1}	119.18 °C
Input air temperature	T_{a2}	17.5 °C
Transverse pitch	S_T	0.08 m
Longitudinal pitch	S_L	0.11 m
Air kinematics viscosity	v	15.2678 * 10^{-6} m^2/s
Gas (air) thermal conductivity	k_{air}	0.0263 W/mK
Air mass density	ρ	1.1614 kg/m^3
Constants in Nusselt number calculation	C	0.330430629Unit less
Constants in Nusselt number calculation		0.6 Unit less
Gas (air) specific heat at constant pressure	cp	1.007 J/kgK
Total number of tubes in the HE bank	N	26 Unit less
Number of tubes in the transverse plane (N_T)	N_T	6Unit less
Pipe diameter	d	0.0501 m
Pipe total length	l	29.3 m

Simulation Output

Calculation of different rates of heat transfer and extraction temperature at different velocities of air flow produced from the air blower can be done using geothermal fluid temperature of 119.18 °C and atmospheric air temperature of 17.5 °C .Tables 2,3 and 4 present the simulation results and the relationships between the velocity of air flow to the rate of heat transfer and honey extraction temperature.

The results in table 2 indicate that different geothermal fluids flow at different rates of heat transfer. The temperature on the outside surface of the heat exchanger pipes is 117.51 - 118.90 °C. In the inner side of the exchanger pipes, the temperature ranges between 118.79 -119.12 °C and the air temperature in contact with heat exchanger pipes ranges between30.77 - 104.45 °C

Table 2: Result of inside and outside pipe surface temperature and air temperature for a constant geothermal fluid temperature

q_r (W)	T_{s1} (°C)	T_{s2} (°C)	T_2 (°C)
1000	119.12	118.90	104.45
2000	119.05	118.62	89.71
3000	118.99	118.34	74.98
4000	118.92	118.07	60.24
5000	118.86	117.79	45.51
6000	118.79	117.51	30.77

Table 3 shows that at various outside surface temperature of HE, the output temperature of the HE would be 40.69 - 45.95 °C, which is enough temperature for hone extraction process. This means that changing the rate of geothermal heat transfer does not produce significant variation in the temperature in the outside of the HE pipes and the resultant HE temperature in the extraction chamber.

Table 3: Tabulation of output (honey extraction) temperature and rate of heat transfer per length of the heat exchanger

T_{s2} (°C)	T_o (°C)	q_{rate} (kW)
118.90	45.95	62.04
118.62	44.91	59.79
118.34	43.86	57.52
118.07	42.81	55.24
117.79	41.75	52.94
117.51	40.69	50.63

Using one value of the rate of geothermal heat transfer for use in the analysis of air flow rate velocities from the air blower ranging from 11.87 to 11.95 m/s, Table 4.3 show the extraction temperature would vary between 40.69 °C to 45.95 °C. This would yield an extraction rate of heat transfer of 50.628 to 62.041 kW in every HE meter length.

Table 4: Relationship between Output (honey extraction) temperature and the rate of heat transfer per length of the heat exchanger.

V (m/s)	T_o (°C)	q_{rate} (kW)
11.850	45.95	62.04
11.854	44.91	59.79
11.858	43.86	57.52
11.862	42.81	55.24
11.866	41.75	52.94
11.870	40.69	50.63

V. Conclusion

The results indicated that different geothermal fluids flow at different rates of heat transfer. The study concluded that there was a relationship between the extraction temperature and the velocity of air flow produced by the blower. The computation of the design system by use of a constant rate of geothermal heat transfer with various air flow velocities 11.95 - 11.87 m/s produces a honey extraction temperature ranging from 40.32 - 45.61 °C. This range is sufficient for honey extraction process. The heat produced in the extraction chamber ranges between50.628 - 62.041kW/m. A conclusion was made that the design system is suitable compared to the existing method of extracting honey due to its suitable means of controlling heat and temperature without overheating honey produced therefore the design system can produce the quality and quantity required in honey production.

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