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Development of a Geothermal Heat-Based System for Honey Extraction Process

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Abstract
In the age of renewable energies, geothermal energy is playing a key role in society. This resource can be utilized either directly or indirectly. Some of the most often used direct application areas of geothermal energy include agriculture, aquaculture, and balneology among others. Honey processing has emerged as a key area where geothermal energy can be applied for societal benefits. This study sought to determine how geothermal energy can be applied in honey extraction and processing. Based on the findings, the bee farmers in Menengai faces challenges during honesty processing mainly wastage. The designed system would help to solve this challenge. The simulation results indicated that, by maintaining certain flow rates of the geothermal water (fluid) and blowing the extracted heat at a given rate, the desired temperature of 40 - 46 °C at which honey is extracted from honeycombs can be achieved. Similarly, fine-tuning the parameters would attain temperatures in the range of 75 °C, which can be beneficial in the preservation of the honey via denaturing of yeast. This system will help to improve honey processing 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 regarded as key necessities for the attainment of improved standards of living across the world. According to Boon and Kankam (2009), shifting the energy production and the way the energy is utilized is of great importance. Currently, geothermal resource has emerged as reliable energy. 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 the early 1900. The different applications of the geothermal energy depends on the chemical composition and thermodynamic properties. 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, the geothermal technology started spreading gradually to other countries and currently, the energy is utilised many countries in different parts of the world. 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 years, honey producers have been faced with challenges in honey processing. The common problem the honey producers have faced over time is loss in honey quality and wastage due to reliance on poor honey processing methods. In the quest for improvement in honey quality and reduction in honey losses during 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 efforst to design a system that utilises geothermal energy for honey processin in a way that minimizes wastge. This system will help to promote honey production in menengai area in Nakuru, an area that has high geothermal potential in the country.

II. Literature Review

Geothermal Energy

Geothermal technologies have 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), the amount of heat contained within 10,000 meters of the earth's surface is estimated to be about 50,000 times that of gas and oil resources in the whole world. This shows that geothermal technology presents 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 USA, Norway, Iceland, China, Japan, Turkey, Germany, and France (Wang *et al.*, 2018). By 2016, globally installed capacity additions of geothermal energy totaled to about 901 megawatts (MW), the highest number which has been recorded in a span of 10 years. With the increasing momentum for the search for sustainable energy sources, a large number of countries are gaining interest in the development of geothermal energy. This increasing popularity of geothermal power is partly due to the increasingly competitive costs for electricity generation from geothermal energy. According to Sigfusson and Uihlein (2015), there is a strong economic case from the deployment of geothermal energy, and the cost is anticipated to continue dropping through 2050.

Geothermal energy is naturally regenerated on a human scale. This energy is thus not affected by global depletion of resources or by the increasing costs of fossil fuels. Geothermal energy is also not dependent on weather, and therefore, 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). Based on the numerous benefits of geothermal energy, the full realization of the potential of this energy would deliver considerable benefits both at the local and international levels. In addition, geothermal power generation brings various benefits such as lower life-cycle of greenhouse gas emissions, lower running costs, the capability to supply base load electricity, flexibility, and ancillary services to a system and higher capacity factors.

The use of geothermal resources depends on the enthalpy and temperature. According to Kiruja (2011), based on the thermodynamic properties, geothermal resources can be grouped as low, 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 various 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 to heat the honey under controlled and low temperatures. The heating helps to lower the moisture content and to destroy all the yeast present in the honey (Sircar & Yadav, 2016)

Applications of Geothermal Energy in Honey Processing

Geothermal energy has presented different solutions in its wide applications. Some of the applications of geothermal energy include drying agricultural produce, air conditioning, and fish farming, among others. Due to the chemical properties of geothermal fluid, it has presented a solution in honey processing. Honey producers have faced the challenges in temperature regulation during honey processing, a challenge that can be solved by designing a system that sues geothermal energy for honey processing. The use of geothermal water helps to heat the honey under controlled and low temperatures. The heating helps to lower the moisture content and to destroy all the yeast present in the honey (Sircar & Yadav, 2016).

III. Methodology

The study was conducted in Menengai area, Nakuru County. This area is about 30 kilometers North of Nakuru County. Bee farming is among the key economic activities in the area. Crop farming is also practiced, but due to the harsh climatic conditions, the crop yields are low and cannot satisfy the economic needs of people. Beekeeping has therefore emerged as an alternative source of income for the people. The climatic conditions in the area are suitable for bee farming, and the practice is fairly embraced by the locals. However, honey production is still low as the beekeepers heavily rely on traditional honey production methods. As a result, the honey produced is of low quality. The purpose of the study was, therefore, 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 processing under controlled conditions.

Purposive sampling technique was used to sample the bee farmers Menengai Crater Beekeepers Association. This is a community-based organization whose key objective is beekeeping, forest protection, and conservation. The respondents were deemed suitable since they have practiced commercial bee farming for quite a long duration and were, therefore, well informed on matters to do with bee farming, honey harvesting, and honey processing. Data from the bee farmers was collected using structured questionnaires and analyzed using the Statistical Package for Social Sciences (SPSS Version 25).Mathematical modeling and simulation, were done using MATLAB and Simulink. The study also involved the design of a system that can utilise geothermal energy to process honey.

IV. Analyses And Results

General Characteristics of Respondents

The general characteristics of the beekeeping respondents were distributed by gender, age, education level, the duration they had been in been in beekeeping, the monthly income obtained from beekeeping, and engagement in other income-generating activities. The findings are presented in Table 1 below.

Table 1: General Characteristics of the respondents

Gender	Male 66.70%	Female 33.3%		
Age	18-35 years 22.3%	36-50 years 44.4%	50 years and above 33.3%	
Education Level	Informal 14.3%	Primary 43.2%	Secondary 33.5%	University/college 9%
Duration in bee Farming	1-2 years 2%	3-4 years 5%	5 years and above 93%	
Monthly income From bee farming	Below Ksh 10,000 67%	Ksh 10,000-Ksh 15000 33%		
Other income-generating activities	Yes 23%	No 77%		

From the findings, the majority of the respondents were males, most were aged between 36-50 years, and the majority had attained primary education. The majority of the bee farmers have been engaged in apiculture 5 years and above and most of them earn below Ksh.10, 000 from beekeeping. The majority of the bee farmers do not engage in other income-generating and apiculture is their key economic activity.

The study established that bee farmers in Menengai mainly rely on traditional methods of honey harvesting and processing. The major methods used include the water bath method, mashing and squeezing honey on clothes, and the use of centrifugal extractors. These approaches are slow, results in incomplete extraction of honey, and leads to the collection of unclean honey that is of low quality. These challenges created the need for an improved system that would ensure the production of high-quality honey and promote honey production.

System Design

The system designed has the ability to minimize wastage during honey processing and regulate the temperature to ensure that the processed honey is of the good quality with the minimal wastage.

Section 1: Heat Energy Equations

The design was modelled as a one-dimensional radial heat flow. From Figure 3 and assuming the system does not generate any energy, the heat transfer equation in the system given by:

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

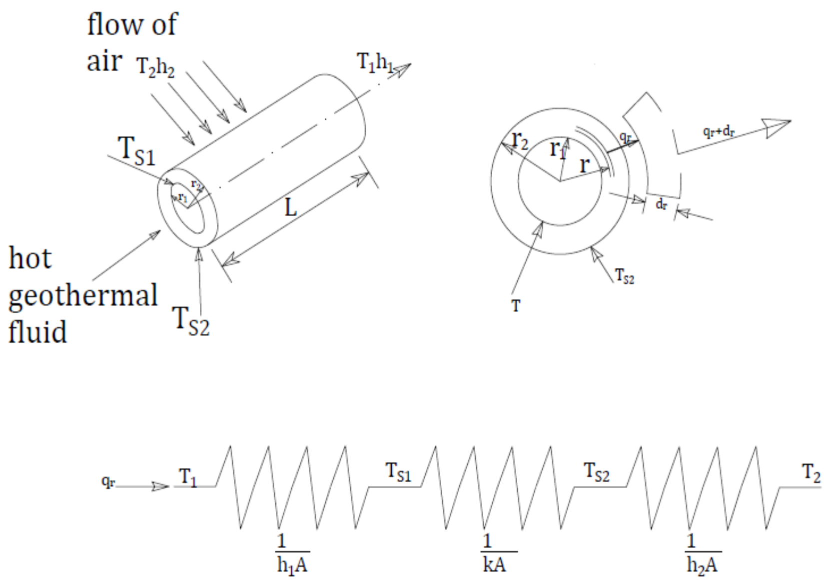

Figure 1: Heat transfer across the heat exchanger pipes **(**Adopted and modified from Incropera, 2005)

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:

i. **$A = 2\pi r L$** = area of the surface normal to the direction of heat transfer.
ii. **q_r** = Heat transfer rate, 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:

$$T_{s1} = C_1\, ln r_1 + C_2$$

And $$T_{s2} = C_1\, ln r_2 + C_2$$

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

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

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

The flow of heat through a cylindrical surface is in the form of logarithmic and not linear due to temperature distribution for a system associated with radial conduction, such as on a flat wall of comparable condition. When equation (iv) is substituted into equation (ii), a general equation of heat rate results as follows:

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

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

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

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

Can also be expressed in heat rate equations for every portion of the whole flow as

$$q_{r1} = 2\pi r_1 l h_1 (T_{a1} - T_{s1}) \qquad \text{(vi.a)}$$

$$q_{r2} = \frac{(T_{s1} - T_{s2})}{ln\left({}^{r_2}/_{r_1}\right)} 2\pi lk \qquad \text{(vi.b)}$$

$$q_{r3} = 2\pi r_2 l h_2 (T_{s2} - T_{a2}) \qquad \text{(vi.c)}$$

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^2K)
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 4). 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 coefficient of the average convection heat transfer (h) can be calculated using the equation given below.

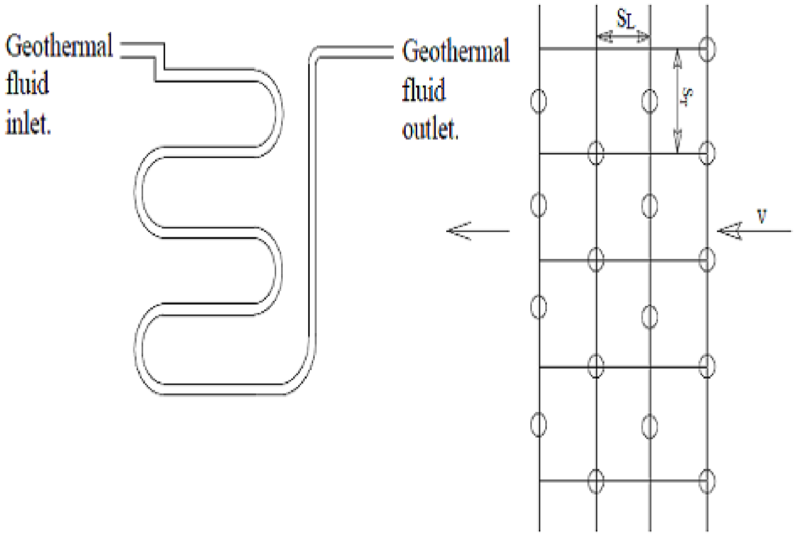

Figure 2: Heat exchanger pipes layout (Adopted and modified from Incropera, 2005)

Zhukauskas Model 1972 proposed a correlation of the form:

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

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 relationships is based on the maximum fluid velocity (Vmax) occurring within the tube bank. For the staggered configuration, the maximum velocity may occur at either the transverse plane or the diagonal plane. If the rows are placed such that:

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

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

Then

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

Heat transfer coefficient (h) can be calculated using 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.

$$\Delta T_{lm} = \frac{(T_{S2} - T_i) - (T_{S2} - T_{o1})}{ln\left(\frac{T_{S2} - T_i}{T_{S2} - T_{o1}}\right)} \qquad \text{(xi)}$$

For which

T_i = temperatures of the fluid as it enters.

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

T_{s2} = temperature of the tube outside the surface.

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

$$\frac{T_{S2} - T_{o1}}{T_{S2} - T_i} = exp\left(-\frac{\pi DN\bar{h}}{\rho VN_T S_T C_P}\right) \qquad \text{(xii)}$$

For:

N = Total number of tubes in the bank.

N_T = number of tubes in the transverse plane.

ρ = air mass density (Kg/m^3).

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

Heat transfer rate per unit length of the tubes is calculated from the following equation:

$$q' = N\left(\bar{h}\Pi D \Delta T_{lm}\right) \quad \text{(xii)}$$

And

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

Design System Parameters

One of the purposes of the study was to simulate system design using the equation in the modeling section. The parameters used in the simulation are:

h_1 = 5000; Geothermal fluid heat convection coefficient (h_i) W/m^{2}K

k = 10; Heat exchanger pipe thermal conductivity (k) W/mK

h_2 = 15; Air heat convection coefficient (h2) W/m^{2}K

T_{a1} = 119.18; Geothermal fluid temperature 119.18 °C

T_{a2} = 17.5; HE Input air temperature (Ti) 17.5 °C

S_T = 0.08; HE transverse pitch (m)

S_L = 0.11; HE longitudinal pitch (m)

v = 15.2678 × 10^{-6}; Air kinematics viscosity 15.2678 m^2/s

k_{air} = 0.0263; Gas (air) thermal conductivity (k_{air}) 0.0263 W/mK

p = 1.1614; Air mass density (ρ, rho) 1.1614 kg/m^3

C = 0.330430629; Constants in Nusselt number calculation (C)

m = 0.6; Constants in Nusselt number calculation (m)

C_p = 1.007; Gas (air) specific heat at constant pressure (cp) 1.007 J/kgK

N = 26; Total number of tubes in the HE bank (N)

N_T = 6; HE number of tubes in the transverse plane (N_T)

D = 0.0501; HE pipe diameter (m)

L = 29.3; HE pipe total length (m)

Simulation Output

Calculation of different rates of heat transfer and extraction temperature at various airflow velocity produced from the air blower can be done using geothermal fluid temperature of 119.18 °C from geothermal well MW 03 at Menengai and atmospheric air temperature of 17.5 °C which is the average temperatures recorded at Nakuru County for the year 2018. Tables 2 and 4 presents the simulation results and the relationship between honey extraction temperatures and airflow velocity to heat transfer rate.

Table 2 shows that at various geothermal fluid flows with various heat transfer rates, the outside surface temperature of the heat exchanger pipes is 117.51 - 118.90 °C. The inside surface temperature of heat exchanger pipes is 119.12 - 118.79 °C and the air temperature in contact with heat exchanger pipes ranges between 104.45 - 30.77 °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 temperatures of HE, the output temperature of the HE would be 40.69 - 45.95 °C, which is sufficient for the honey extraction process. This implies that changing the rate of geothermal heat transfer does not cause a remarkable range of outside temperature of the HE pipes and output temperature of the HE in the extraction chamber.

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

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

By picking one value of the rate of geothermal heat transfer to be utilised for analysis of airflow rate velocities from the air blower to be between 11.95 to 11.87 m/s, Table 4 shows the extraction temperature would vary between 40.69 °C to 45.95 °C, which will produce an extraction rate of heat transfer of 50.63 to 62.04 kW per meter length of the HE.

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

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

Based on the findings, the beekeepers in Menengai area face numerous challenges that impact on the quality of honey collected. The common challenge is the beekeepers' overreliance on traditional methods. Besides impacting the quality and quantity of the honey collected, the methods are time-consuming thus limiting honey production only to small scale. Therefore, the use of the designed honey collection and processing system will be a big boost to the honey industry. Apart from ensuring honey quality, the system will minimize wastage and promote large scale production of honey and growth in the Kenyan honey industry besides spurring economic growth for the communities.

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