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Use of Solar Energy for Recycling Honeycombs

Ahmed M. Elsheikha[1]; Mohamed A. Al-Rajhi[2] and Sara M. El-Serey[1]

[1]Agric. and Biosystems Eng. Dept., Fac. of Agric., Damietta University, Damietta, Egypt.

[2]Agric. Eng. Research Institute, Agriculture Research Center, Giza, Egypt

Corresponding author*: saramoufied2020@gmail.com. Mobile No. 01001597526

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ABSTRACT

Honeycombs should be changed regularly as they become old, damaged and contain the causative organism of many bee diseases, such as European foul brood (EFB), American foul brood (AFB) and Nosema. This research aims to use solar energy for recycling old combs and capping wax byproduct to produce raw beeswax in a simple and cheap way using solar energy as a source of heating. A water bath was typically used as the first approach, then two solar-powered wax melters—one that used only solar energy and the other that used solar energy and additional heat from solar panels—with hot air moving at an average speed of 0.8 m/s and a temperature of 45 ˚C. The parameters that studied in this present work were included silicone molds to create beeswax in three different beeswax thicknesses (1, 1.5, and 2 cm) and three various heights of perforated tray (5, 10, and 15 cm). First according to the experimental findings, the efficiency of melting beeswax when done traditionally in a water bath was determined to be 73.4%, compared to 85.5% and 87.2% for the first and second solar systems, respectively. However, while the wax melted using a solar-powered wax melter, various measures of macroclimatic parameters such as solar radiation, ambient temperature, and relative humidity for inside and outside were registered. Additionally, during the experimentation, the color properties of the molten beeswax were estimated and analyzed as red (R), green (G), blue (B), lightness (L^*), redness (a^*), yellowness (b^*), chrome (C^*), and hue angle (H°). The averaged values for the traditional method were 197.50, 144.81, 51.81, 63.53, 11.02, 54.49, 55.81˚ and 79.21˚, respectively, and 251.25, 188.50, 46, 80.14,10.80, 74.07, 74.85˚ and 81.70˚ for first solar system, and 245.75, 216, 145, 87.34, 0.85, 38.77, 38.78˚ and 88.74˚ for second solar system.

INTRODUCTION

Honeybees need wax to construct their combs. Wax produced in the outline of thin scales from their wax glands at a certain age, which are fully developed in 12 to 18 days old workers on the ventral surface of the stomach. These bees have 8 wax producing glands. About 8 pounds (3.629 kg) of honey is consumed by bees to produce one pound (0.455 kg) of beeswax. Beeswax is a worthy product that can provide a worthwhile income in addition to honey. One kilogram of beeswax is valuable more than one kilogram of honey. Unlike honey, beeswax is not a food product and is easier to deal with and no delicate packaging required which this simplifies transport and storage, **Bradbear, (2009).** In addition, it can be used to make candles and polish, among other things. It can also be converted into "foundation" sheets, which are delicate wax sheets. Nowadays, most wax is produced for the manufacture of cosmetics, such as depilatory wax, hand and face creams, lipsticks, and other items. The pharmaceutical industry also employs the wax to coat a range of ointments, pills, suppositories, and other industrial goods. On the international market, honey costs three times as much per unit as beeswax, according to **Gemeda and Kebebe (2019).**

Based on **FAO, (2022)** estimates 62,166 ton of beeswax produced in 2020 Asia, Africa and America's production were estimated to be 31,898 ton (51%), 16,186 ton (26%) and 13,519 ton (22%), respectively. As for Egypt in particular, beeswax production in 2020 is amounted to 113 ton, and exports quantities are amounted to 61 ton with a value of 111 thousand US$, while imports quantities amounted to 57 ton with a value of 242 thousand US$. The following figure shows the fluctuation of Egypt's production of beeswax from 2000 to 2020, which totaled only 2,561 ton.

Beeswax is the creamy colored substance used by bees to build the comb that forms their nest structure. The color of pure beeswax is white or yellow to yellow brown, depending on relative quantity of propolis pigments, pollen and other substances cause it to change color. The wax extraction can be divided into melting and chemical extraction methods, **Sin et al., (2014).** Wax can also be obtained from old honeycomb. Tiny pieces of comb can include wax capping, frames, and hive pieces that are taken out before the honey is extracted from the comb. Between 62 and 65 ˚C are the melting points, and a substantial amount of energy is needed to melt it. Wax becomes flexible as it melts because it already softens around 35 ˚C. As a result, in order to obtain pure wax from the comb, it must first be separated from various contaminants by melting the wax out of the comb using heat from the sun, hot water, or steam, **Mutsaers, et al. (2005).** The electrical and solar heat supplied methods are used since they are not complicate to design and manufacture the melter system. Regarding different densities, the beeswax is melted by boiling in water or steam, and then filtering. Aluminum or stainless-steel containers are appropriate as well for avoiding the darkening; the beeswax should not directly contact the heat source, **Bogdanov, (2009).** Beeswax absorbs the thermal as applied energy ever after energy starts affecting the intermolecular bonds, the melting initially occurs. The onset of melting point is in range of 30 to 62 ˚C as well the temperature range of the phase change is between 18 to 32 ˚C approximately, **Khamdaeng et al., (2016).**

Furthermore, Egypt receives a lot of sunlight. According to the solar atlas, Egypt receives 3050 hours of sunlight on average each year, with direct normal irradiations varying from 1970 to 3200 kWh/m^2 annually and annualized total solar irradiance varying from 2000 to 3200 kWh/m^2. Egypt therefore has amazing solar resources that can be used for a wide range of solar energy systems and industries, including the construction of photovoltaic (PV) or concentrated solar power (CSP) plant setups, **Moharram et al., (2022).** Notably, solar energy is one of the most effective options among all renewable energy sources because it is non-polluting, free, and abundant for the majority of the year with tolerable radiation intensity. Since there aren't many studies on utilizing a solar melter to recycle beeswax in Egypt, this research was done to determine an economical (energy is free) and efficient way to melt and filter beeswax. The ultimate objective was to produce high-quality wax blocks that could either be exported or used locally in successful commercial companies.

MATERIAL AND METHODS

The experiments were conducted from August 30 to September 12 of 2022, a study on the impact of solar energy on the melting of crude beeswax was conducted outside at Damietta University's Faculty of Agriculture, which is astronomically located at latitude 31.4224˚N and longitude 31.6575˚E. Ambient temperatures, solar radiation intensities, temperatures within and outside of the experiment unit, the process of melting the wax under study during daylight hours, and the occurrence of changes in the readings of these factors were all measured from 07:00 to 17:00.

2.1. Materials:

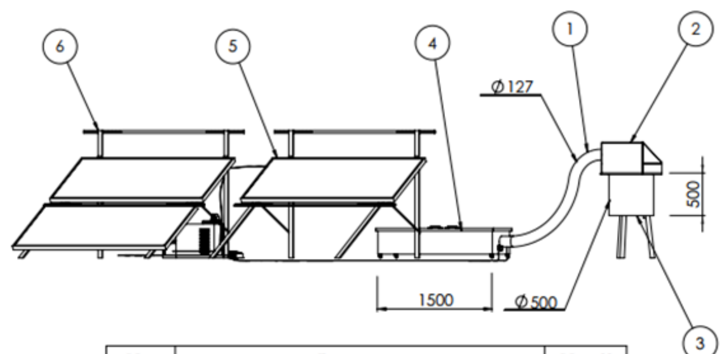
2.1.1. Crude Beeswax

Sources of wax included old brood frames, pressed remains from the heather press, and cappings. Old brood combs usually produce dirty wax, while capping produces clean wax. The beeswax being studied is produced by the hybrid carniolan honey bee (Apis mellifera carnica) in June 2022 harvest season, crude beeswax —an impure wax that includes dead bees during the collecting and harvesting activities— was obtained from an apiary in Damietta city after sifting the honey from the combs, as shown in **Fig. 1-A**, and it was used in the melting processes to create wax in blocks weighing a few kilograms as shown in **Fig. 1-B**.

Fig. 1. Beeswax before and after Melting Process

2.1.2. Solar-Powered Wax Melter

The solar wax extractor offers an efficient and rapid way to melt and clean beeswax, raising the interior temperature to 68–70 °C to sufficiently melt the beeswax. As demonstrated by the elevation view in **Fig. 2.**, and the realistic perspective in **Fig. 3.**, the device is made up of the components stated below.



No.	Part name	No.off
1	Aluminum Pipe 5 in	1
2	Lean-to architectural Form	1
3	Stainless-steel Tank	1
4	Solar heater (Wooden heater)	1
5	Solar photovoltaic panels	3
6	Stand	2

Fig. 2. Sketch Elevation View of Solar-Powered Wax Melter

Fig. 3. Overall view of the tested Solar-powered Wax Melter

2.1.2.1. Stainless Steel Tank

The tank is a cylindrical design with a 50 cm diameter and 50 cm depth, and its exterior was thermally insulation to prevent heat loss via the sides. It has a stainless-steel perforated tray with a surface area of 19.63 cm^2 and a 10 mm diameter inside that is designed to place the formed wax discs.

2.1.2.2. Lean-to Architectural Form

The wooden structural frame's dimensions are depicted in **Fig. 4.** In order to enhance the amount of solar radiation entering the extractor, it was completely covered with 2 mm-thick polycarbonates, with the exception of the back reflector, which was covered by nickel-chrome.

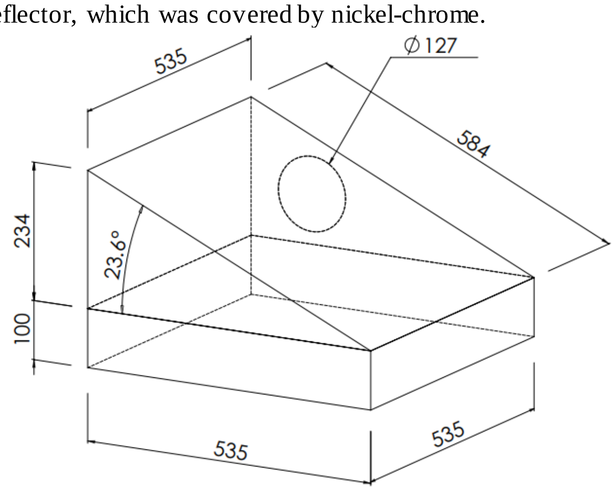


Fig. 4. Sketch for the design of a lean-to architectural form

2.1.2.3. Solar Heater (Wooden Heater)

The solar heater was constructed using a thermal coil that was placed on stainless steel screws inside a wooden box that was lined on the inside with fiberglass, with a ceramic plate providing an insulator below the thermal coil prevent burning.

2.1.2.4. Solar Photovoltaic System

For a PV panel that is composed of three JSM-385M72 modules. They were installed on a rectangular metal frame at the proper 30° slope from the horizontal plane in parallel.

2.2. Methods:

The experimental work was intended to melt the beeswax using a water bath as a traditional process for later comparison with the solar energy method of, by filling about half of an aluminum pan with water before it is heated on the stove, putting about 500 gm of the beeswax in a smaller aluminum pan, and then, placing the smaller pan inside the larger pan and warm over medium heat until the beeswax melts. On the other hand, utilizing a solar-powered wax melter that heated combs directly from the sun (natural melting). This method can be used to produce raw wax without the need for comb storage. It was utilized in two different ways: first, depending only on solar energy, and second, depending on solar energy with additional heat from solar panels with hot air moving at an average speed of 0.8 m/sec and temperature of 45°C.

2.2.1. Designing the Lean-to Architectural Form

For designing the lean-to architectural form, it is necessary to calculate the optimum tilt angle of an inclined surface to receive the most solar radiation possible by using the following equations, **Duffie and Beckman, (2013).**

$$\beta_o = \cos^{-1}\left[\cos(\Phi)\cos(\delta)\cos(\omega) + \sin(\phi)\sin(\delta)\right] \quad (1)$$

$$\delta = 23.45\sin\left((360) + \left(\frac{284+n}{365}\right)\right) \quad (2)$$

Where:

(ϕ) is a latitude angle = 31.42° for New Damietta (study location).

(ω) is a solar hour angle = 15 (LAT – 12), LAT is local apparent time

(δ) is a solar declination angle, (n) the day after January 1st.

2.2.2. Color Analysis

As the pure beeswax solidified, it was removed from the mold. A color analyzer that uses the abbreviations R (red), G (green), and B (blue) was used to determine the color RGB of the melted beeswax samples. The sample image's RGB color space must then be converted Cie-L*ab. Thus, using the following equations, the purity and hue angle were determined, **Khamdaeng et al., (2016).**

$$C^* = \sqrt{(a^*)^2 + (b^*)^2} \quad (3)$$

$$H^\circ = \tan^{-1}\left(\frac{b^*}{a^*}\right) \quad (4)$$

Where:

a^* indicates red/green coordinate.

b^* indicates yellow/blue coordinate.

C^* indicates chroma.

2.2.3. Melting Efficiency (EFF %)

The melting efficiency, EFF%, was defined as following Equation, **Khamdaeng et al., (2016).**

$$EFF\% = \frac{M_i - M_f}{M_i} \times 100 \quad (5)$$

Where:

M_i is initial mass of selected beeswax (500 g).

M_f is mass of impurities residual after melting process.

2.2.4. System Efficiency (η_c)

The efficiency of the solar wax extractor was defined as following Equation, **Khan et al., (2019).**

$$\eta_c = \frac{P_{out}}{P_{in}} = \frac{(mC_pT + mL)}{P_{in}} = \frac{(mC_p\Delta T + mL)}{A_c\, I_b} \quad (6)$$

Where:

η_c: is efficiency of the system, %

m: is melting wax per hour, (kg/hr).

$\Delta T = T_f - T_i$, (T_i initial temp of beeswax and T_f final (melting) temp).

C_p: Specific heat of beeswax, (0.476 KJ/kg.K).

L: Latent heat of fusion of the beeswax, (242.8191 KJ/kg).

Ac: Collector area, m^2.

I_b: Beam radiation, W/m^2.

P_{out}: Output power, W.

P_{in}: Input power, W.

2.2.5. Cost Analysis

A cost analysis was done on the solar-powered wax melter that was constructed and used in this experimental research. After calculating the fixed costs, variable costs, and defining the selling price per unit for output. Some of the financial and economic tools were calculated as follows **(Farris, et al. 2015).**

$$CM = P - V \quad (7)$$

$$CMR = \frac{CM}{P} \quad (8)$$

$$BEU = \frac{TFC}{CMR} \quad (9)$$

$$BES = \frac{TFC}{CMR} \quad (10)$$

Where:

CM: Contribution margin

CMR: Contribution margin ratio.

P: selling price per unit, (225 EGP).

V: total variable cost (per unit).

TFC: total fixed cost (per unit).

BEU: Break-even units.

BES: Break-even sales.

2.2.6. Experimental treatments:

It was initially performed using a water bath as a typical method, followed by two systems by using a solar-powered wax melter first, depending only on solar energy, and second, depending on solar energy and extra heat from solar panels with hot air moving at an average speed of 0.8 m/sec and temperature of 45 ˚C. The following elements were included in the treatments for this technique as depicted:

1. Using silicone molds to form beeswax into a specific thickness.
2. Beeswax of three different thicknesses (1, 1.5, and 2 cm).
3. Perforated tray in three different heights (5, 10, and 15 cm).

2.2.7. Experimental Measurements:

2.2.7.1. During Water Bath Method:

- Bulk temperature of molten beeswax over process.
- Efficiency of melting process.

2.2.7.2. During Solar-Powered Wax Melter Method:

- Time of beeswax melting.
- Efficiency of melting process.
- Solar radiation incident.
- Ambient temperature.
- Relative Humidity.
- Bulk temperature of molten beeswax.
- Performance Analysis: Mass flow rate of beeswax with system efficiency.
- Beeswax Color Analysis.
- Cost Analysis.

2.2.8. Statistical analysis

The experiments were replicated three times. The data were statistically analyzed using the Costat Program, **(Oida, 1997)** to determine the statistical significance of the variables under consideration based on the probability ($P<0.05$).

RESULTS AND DISCUSSION

3.1. Water bath method

It's one of the conventional techniques for melting beeswax. The bulk temperature of beeswax changes from a solid state at room temperature (28.9 °C) to a liquid condition at an average temperature of 63.01 °C in an average of 30.5 minutes. For the effectiveness of the wax melting process ranged from 65.1% to 77.7%, with an average of 73.4%. However, the color properties of the molten beeswax were estimated and analyzed as red (R), green (g), blue (b), lightness (L^*), redness (a^*), yellowness (b^*), chrome (C^*), and hue angle (H°). The averaged values were, respectively, 197.50, 144.81, 51.81, 63.53, 11.02, 54.49, 55.81˚ and 79.21˚.

The melting point result is also consistent with findings from **Krell (1996); Nuru (2007) and Bogdanov (2016),** who discovered that the melting point ranged from 61 to 66 ˚C, or ideally, between 62 and 65 ˚C.

3.2. Solar-Powered Wax Melter

Solar-powered wax melter was used to melting a crude beeswax through two solar system, at first, only solar rays collected from the surface of the extractor were used, and then additional heat energy was added from external solar heater, with an average temperature of 45 ˚C and an average speed of 0.8 m/sec. And the results of experimental work were as follow.

3.2.1. The Solar Melting Process of Beeswax

The melting time for the first system varied from 150 to 360 minutes, with an average of 243.3 minutes, whereas the melting time for the second system ranged from 90 to 240 minutes, with an average of 183.3 minutes. Furthermore, the experimental calculation of beeswax melting efficiency (%EFF) for first system ranged from 66.9% to 95.1%, with an average of 85.5%, and for second system ranged from 81.4% to 92.1%, with an average of 87.2%.

Thus, the findings demonstrated that the solar-powered wax melter outperformed the conventional water bath method in terms of beeswax melting efficiency.

3.2.2. Incident of Solar Radiation Flux:

Since the solar energy used in this research is the primary source of heating energy for melting beeswax and that it continuously varies from day to day and hour to hour depending on the sky's conditions (clouds and fog), time of day, and weather, its use requires sophisticated control. Total incident solar radiation is measured and recorded on inside and outside the solar. So, the incident solar radiation for the first six days of practical experiments, from August 30 to September 6, ranged from 70 to 1037 W/m^2 inside, compared to 84 to 1310 W/m^2 outside. In addition, the hourly average solar radiation that was available outside and inside was 801.55 (± 21.56) and 622.15 (± 29.41) W/m^2, respectively. While in the second system, from September 7 to September 12, it ranged from 50 to 1014 W/m^2 inside, as opposed to 67 to 1190 W/m^2 outside, and that the hourly average solar radiation that was available outside and inside during the experimental period was 776.60 (±17.18) and 607.20 (±28.39) W/m^2, respectively. So, **Fig. 5. and Fig. 6.** display the variation in incident solar radiation that was measured and recorded outside, inside, and reflected from the vertical-back wall during the experimental work.

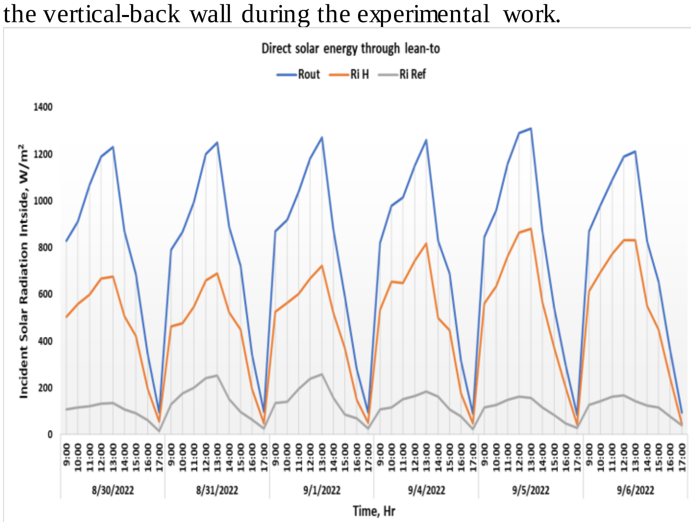


Fig. 5. Daily fluctuations in incident solar radiation, inside and outside the Lean-to solar extractor (First System).

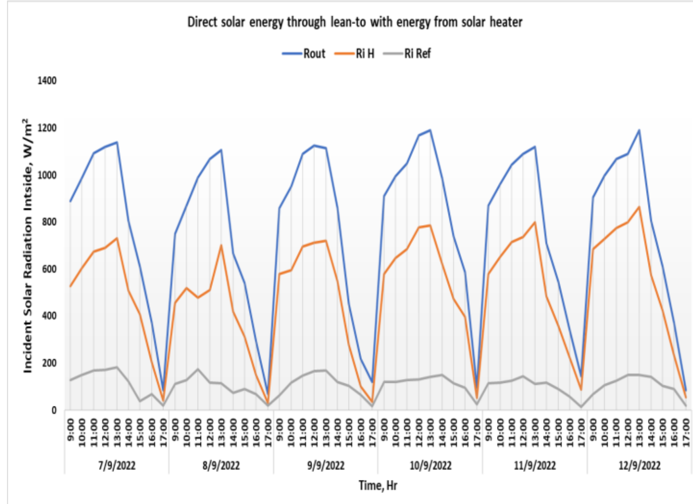


Fig. 6. Daily fluctuations in incident solar radiation, inside and outside the Lean-to solar extractor (Second System).

According to the data results the polycarbonate cover of the solar extractor has a clear impact on incident solar radiation inside for two experimental systems. So, the following **Fig. 7. and Fig. 8.** show the relationship between incident solar energy inside the solar collector and outside.

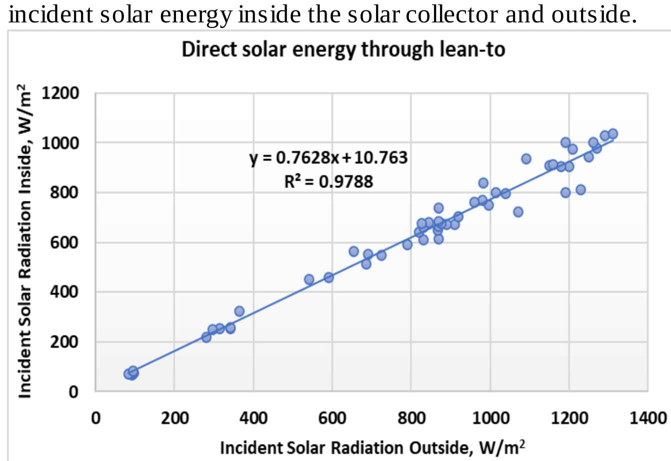


Fig. 7. Incident solar radiation internal the solar extractor against incident solar radiation external (First System).

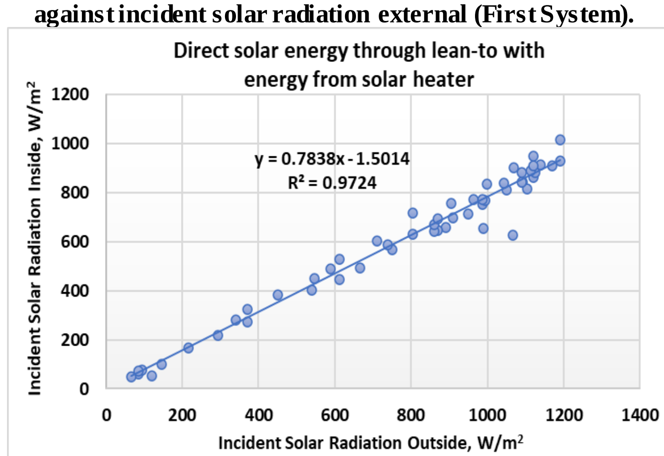


Fig. 8. Incident solar radiation internal the solar extractor against incident solar radiation external (Second System).

3.2.3. Ambient temperature

A substance's phase can change from solid to liquid through a physical process known as melting or fusing. This takes place whenever the solid's internal energy rises, frequently because of heat being applied, which elevates the temperature of the material to its melting temperature, **Sofekun, et al., (2018).** So, in the case of melting beeswax, heat is required to raise its temperature to that of melting. However, for the melting to occur, additional heat must be provided by the heat of fusion, a particular sort of latent heat.

As a result, it has been discovered that the hourly average ambient temperatures outside and inside the lean-to solar extractor for the first system were 29.85 ˚C (± 0.13) and 46.91 ˚C (± 0.86) whereas for the second system they were 29.84 ˚C (± 0.15) and 46.25 ˚C (± 1.65). Also, the first and second systems' respective increasing ambient temperature percentages were 57.14% and 55%.

Additionally, form data analysis it was show the significant influence of inside ambient temperature (T_{ai}) on the bulk temperature of beeswax (T_{bulk}) using a lean-to solar extractor technique under particular conditions during the experimental processes as shown in **Fig. 9. and Fig 10.**

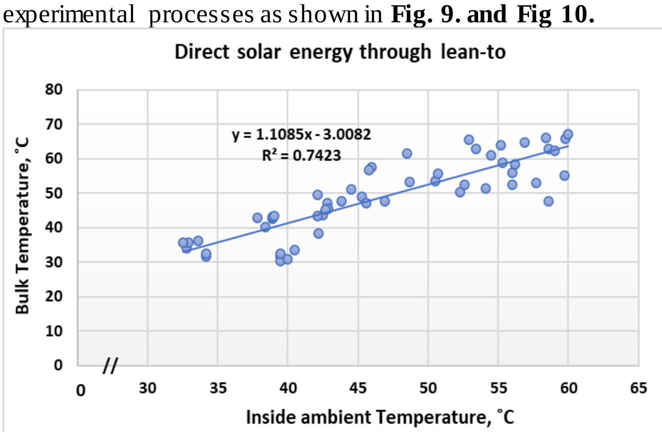


Fig. 9. Bulk temperature of grape beeswax against inside ambient temperature for the Lean-to solar extractor (First System)

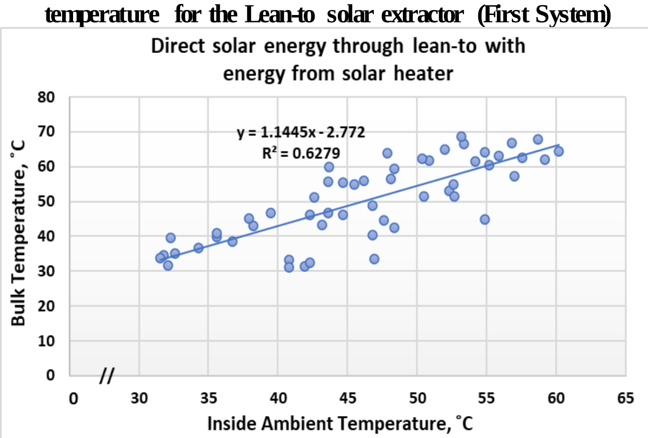


Fig. 10. Bulk temperature of grape beeswax against inside ambient temperature for the Lean-to solar extractor (Second System)

3.2.4. Relative Humidity

The hourly average air relative humidity inside and outside the solar extractor, respectively, was 36.10% (± 1.16) and 68.71% (± 1.50), whereas in the second system, both inside and outside the solar extractor had hourly average relative humidity readings of 38.28% (± 2.41) and 71.24% (± 1.90), respectively. The solar extractor decreased the relative humidity of the inside air for the two systems by 32.61% and 32.96%, respectively.

In light of this, the results showed that particularly during the daytime, the air temperature and relative humidity are inversely related. Moreover, a solar extractor may increase the inside temperature above the external temperature while simultaneously reducing the internal relative humidity below the external relative humidity was assessed. As a result, melting times are shortened, and ambient air's capacity to carry on more water vapor from the product being melted is increased.

3.2.5. System Efficiency

Efficiency for the first system varied between 31.4% and 61.6%, with an average of 44.1%. Nevertheless, the efficacy of the second system was between 44.1% and 76.6%, with an average of 59.2%. Also, it's found that the efficiency of the system is significantly influenced by the macroclimatic conditions around the solar extractor. So, **Fig. 11., Fig. 12. and Fig. 13.** show the direct correlation between efficiency and incident solar radiation, ambient temperature, and relative humidity.

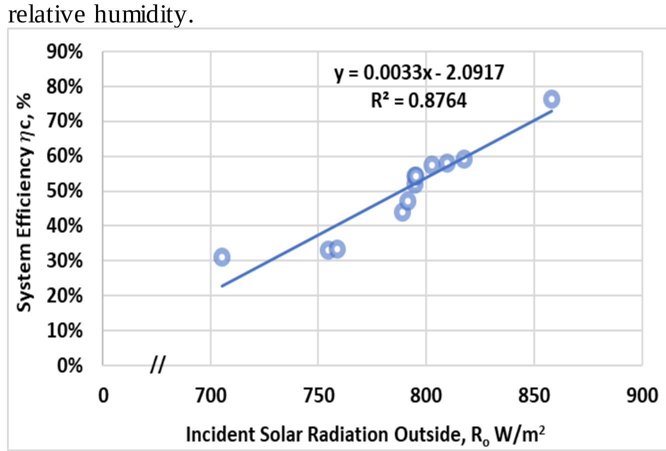


Fig. 11. Efficiency versus Avg. Incident Solar Radiation

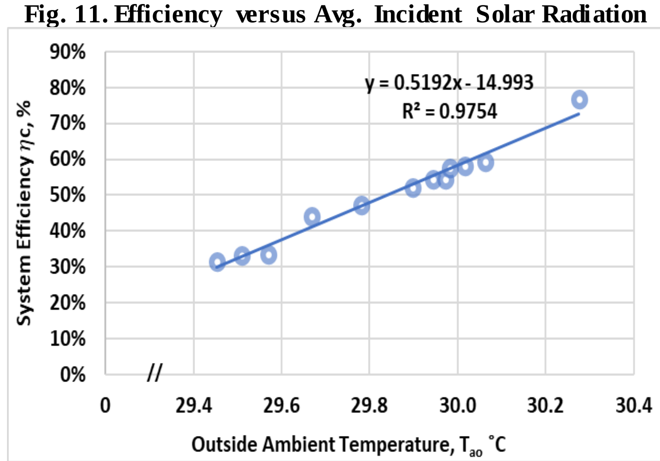


Fig. 12. Efficiency versus Avg. Ambient Temperature

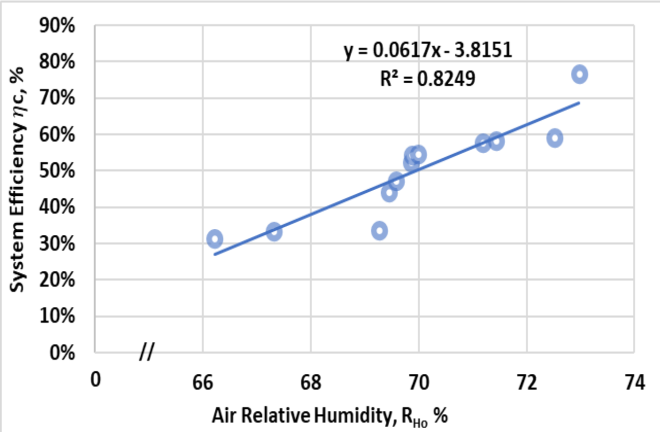


Fig. 13. Efficiency versus Avg. Relative Humidity

These findings concur with those of **Khan et al., (2019),** who revealed a direct correlation between daily candle output, kg, and the change of average solar beam radiation, W/m^2 by heating and melting paraffin or beeswax using solar energy. As well, they discovered that the efficiency of melting is directly related to beam radiation, and it depends on ambient temperature.

3.2.6. Color Analysis

During the experimentation, the color properties of the molten beeswax were estimated and analyzed as red (R), green (g), blue (b), lightness (L^*), redness (a^*), yellowness (b^*), chrome (C^*), and hue angle (H°). The averaged values were, respectively, 251.25, 188.50, 46, 80.14, 10.80, 74.07, 74.85° and 81.70° for first solar system, as well were 245.75, 216, 145, 87.34, 0.85, 38.77, 38.78° and 88.74° for second solar system.

Similar findings were also published by **Khamdaeng et al., (2016)** who discovered that they were the factors causing the ideal beeswax color ($L^* \geq 39$, $C^* \geq 30.88$ and $45^\circ \leq H^\circ \leq 90^\circ$).

3.2.7. Cost Analysis

The total initial cost for the solar-powered wax melter is around 6,800 EGP. Whilst the overall variable expenses for the solar melter employed during the melting process consequently came to around 218.38 EGP. Also, it was found that the contribution margin per unit was 6.63 EGP, or the additional revenue earned for each sold unit after subtracting the variable share of costs, with a contribution margin ratio of 2.9%. On the other hand, it was discovered that 1027 units would be required to break even, which means that no money would be lost but there would also be no profit. Additionally, 230493.40 EGP worth of beeswax had to be produced and sold to cover all production-related expenses.

CONCLUSION

A study was done to find out if it was possible to melt crude beeswax using solar energy to produce a high-quality beeswax block with readily available, sustainable energy. Because there is a realistic method by which the raw material can be melted, filtered, and formed like discs can be used in numerous sectors or exported abroad, this study encourages beekeepers in Egypt to take care not to neglect and collect this product. In contrast, the first system had a good efficiency that ranged from 31.4% to 61.6% on average 44.1%. It was demonstrated that a simplistic device may be created to melt beeswax on-hand, to protect it from degrading and being attacked by insects, with simple capabilities and at a fair cost.

FUNDING:

This research did not receive any funding.

CONFLICT OF INTEREST:

The authors declare that they have no conflict of interest.

AUTHORS CONTRIBUTION

All authors developed the concept of the manuscript. **El-Serey** wrote the manuscript and achieved the experimental work and measurements. All authors checked and confirmed the final revised manuscript.

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استخدام الطاقة الشمسية في إعادة تدوير أقراص شمع العسل

أحمد محمد أحمد الشيخة[1] محمد علي إبراهيم الراجحي[2] سارة مفيد بديع الصيري[1]

[1] قسم هندسة النظم الزراعية والحيوية - كلية الزراعة – جامعة دمياط – مصر
[2] معهد بحوث الهندسة الزراعية - مركز البحوث الزراعية – الجيزة – مصر

يعتبر شمع العسل منتجاً قيماً يمكن أن يعطي ربحاً وهو أحد الشموع الحيوانية تفرزه الشغالات باستخدام ثماني غدد خاصة تقع على الأربع حلقات الأخيرة من الجهة البطنية. تشكل الكحوليات طويلة السلسلة وإسترات الأحماض الدهنية معظم التركيب الكيميائي لشمع العسل، حيث يستخدم شمع النحل في العديد من التطبيقات التجارية بما في ذلك الأساسات الشمعية ومستحضرات التجميل، والأدوية، وشموع الاضاءة وأيضاً في صناعة الأغذية. شمع النحل هو مادة ذات لون كريمي يختلف اللون اعتمادًا على الصبغات الموجودة في البروبوليس وحبوب اللقاح والأشياء الأخرى التي تتسبب في تغيير لونها، يمكن أن يكون شمع النحل النقي أبيض أو أصفر أو أصفر يميل للبني. تتعدد طرق استخلاص شمع النحل إما عن طريق صهر الشمع أو بالاستخلاص الكيميائي.

أجريت هذه الدراسة في كلية الزراعة جامعة دمياط، والتي إحداثياتها على خط عرض 31.4224 درجة شمالاً وخط طول 31.6575 درجة شرقاً، وذلك في الفترة من 30 أغسطس إلى 12 سبتمبر لعام 2022. الهدف الرئيسي من الدراسة هو إذابة شمع العسل الخام باستخدام الطاقة الشمسية والحصول على أقراص شمعية عالية الجودة من خلال طاقة مستدامة متاحة معظم شهور العام وسهلة الاستخدام. إن كتل شمع العسل عالية الجودة ذات الطاقة المستدامة سهلة الاستخدام والمتاحة دائمًا هي الهدف الرئيسي لهذا الإجراء.

وقد شملت الأهداف الخاصة ما يلي:

1. تصميم جهاز لاستخلاص الشمع الشمسي فعال من حيث التكلفة لإنتاج أقراص من الشمع.
2. دراسة خصائص الطاقة الشمسية ومتغيرات الدراسة التي تؤثر على كمية الإشعاع الشمسي.
3. حساب كفاءة الإنتاج لمستخرج الشمع الشمسي.
4. مقارنة النتائج بين الطريقة التقليدية والمستخرج الشمسي في استخلاص شمع النحل.
5. التحليل الاقتصادي لمستخرج الشمع من خلال دراسة التكاليف الثابتة وتكاليف عملية الصهر (تكاليف متغيرة).

تم إجراء عملية الصهر في البداية باستخدام حمام مائي كإحدى الطرق التقليدية، كذلك استخدام جهاز الاستخراج الشمسي بنظامين الأول يعمل بالطاقة الشمسية فقط، والثاني يعتمد على الطاقة الشمسية بالإضافة إلى حرارة إضافية من الألواح الشمسية عن طريق هواء الساخن متوسط درجة حرارته 45°م بسرعة متوسطها 0.8 م/ثانية .

وشملت معاملات الدراسة ما يلي:

1. استخدام قوالب من السيليكون لتشكيل شمع العسل بسمك معين ومساحة تعرض ثابتة.
2. ثلاث معاملات مختلفة من سمك أقراص شمع النحل (1 - 1.5 - 2 سم).
3. ثلاث ارتفاعات مختلفة للصينية المثقبة المثبت عليها أقراص شمع النحل (5 - 10 - 15 سم).

أظهرت النتائج التجريبية أن متوسط كفاءة ذوبان الشمع أثناء عملية الصهر التقليدية باستخدام طريقة الحمام المائي 73.4% بينما في حالة استخدام جهاز الاستخراج الشمسي حققت 85.5% للنظام الأول و78.2% للنظام الثاني.

كما أظهرت النتائج المتحصل عليها من التحليل اللوني للشمع المنصهر أن متوسط قيم RGB و LAB وقيم الكروم C^* ودرجة اللون H^* في حالة طريقة الصهر التقليدية 197.50 - 144.81 - 51.81 - 63.53 - 11.02 - 54.49 - 55.81° - 79.21° على التوالي بينما كانت في حالة استخدام جهاز الاستخراج الشمسي 251.25 - 188.50 - 46 - 80.14 - 10.80 - 74.07 - 74.85° - 81.70° للنظام الشمسي الأول أما النظام الثاني 245.75 - 216 - 145 - 87.34 - 0.85 - 38.77 - 38.78° - 88.74°.

الكلمات المفتاحية: طاقة شمسية – إذابة شمع النحل – كفاءة عملية الإذابة – تصميم Lean-to

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