SOLAR ENERGY UTILIZATION FOR MILK PASTEURIZATION

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ABSTRACT

A design and performance analysis of pasteurization system that is based on the solar energy as a thermal source for pasteurizing the milk has been done. It is adapted for using at remote areas and village communities where the small quantities of milk delivered by individual producers who are deprived of the availability of electricity and gas. A solar flat plate collector was used as milk pasteurizer. The pasteurization temperatures were 63 and 72°C. The solar milk pasteurizer, during September, October and November 2009, attained pasteurization temperatures in 3 to 19 minutes depending on the solar radiation, and the desired temperature for pasteurization. The average daily maximum amount of solar-pasteurized milk was 73.9 l at 63°C, while the minimum was 37.3 l at 72°C. The change in intensity of solar radiation had a direct impact on solar milk pasteurizer.

INTRODUCTION

The milk and its products are fundamental in human nutrition. It can be used as an important part of his diet throughout life. The milk is a perishable foodstuff because it is an excellent medium for the growth of microorganisms which cause spoilage. Heating milk to a specific temperature for a specific period of time, lead to killing harmful microorganisms. For example, milk heated to 65 °C for 30 minutes, for making safe milk. This process is called pasteurization, **Robinson, (2002)**. Energy is needed for doing the previous process, even at a very modest scale of operations. However, energy from conventional sources is becoming increasingly expensive, **Tuszynski et al. (1983)**.

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Capturing the sun's energy may be a logical solution to solve the energy problem caused by scarce fuels. It is free and has negative impact on the environment.

Egypt is located in areas where solar energy is abundant, **Sorensen (2003)**, based on **NCEP-NCAR (1998)**. The annual solar radiation on Egypt ranges from 5 to 8 kWh/m^2 per day; with about 3000 sunshine hours per year in northern region (about 300 days per year), and about 4000 sunshine hours per year in southern region (almost all the days of the year), **El-Shahat (1999)** cited from **El-Sayed (1993)**, and **Sayigh (1977)**. Thus, the abundance of solar energy paired with the concept of milk pasteurization promotes a new solution to purifying unsafe milk. This solution has the following advantages: environment conservation, ensure a better human health in remote areas, address the problem of energy and reduce costly, a new use of solar energy applications and the cost of such energy is low which is required only for the necessary apparatus to establishing it. Long distances between the production areas and the markets, bad road conditions and high ambient temperatures make the development of a dairy industry to be a particularly difficult task. Therefore, this research aims to apply solar energy for pasteurizing the milk at remote areas and in village communities which are deprived of the availability of electricity and gas, where the small quantities of milk are delivered by individual producers.

The solar energy collectors are special kind of heat exchangers that transform solar radiation energy to internal energy of the transport medium. The flat-plate solar collector is one of the most important types of solar collectors because it is the simplest one and has a wide range of important potential applications, **ASHRAE (1995)**.

The average daily milk production of cows is about 4 kg per head in the winter and about 2.8 kg in the summer. For the buffalo, the average daily milk in the winter is about 6.6 kg per head and about 5.2 kg per head in the summer. The average annual productivity is about 3.1 kg per cow, and about 5.9 kg per buffalo. Therefore, about 80 % of Egypt's production of milk is produced during the winter and spring, **El-Shebley et al. (2003)**.

Franco et al. (2007) have designed a system for pasteurizing 10 *l* of milk in about 1 hour. The system was made of a Fresnel type concentrator with a vaporizer located in the focus. The steam bubbles into the isolated container where the milk is cooked by a double boiler.

Zahira et al. (2009) have fabricated a solar milk pasteurizer from standard appliance shipping cardboard with multiple layers of the regular aluminum foil glued onto cardboard which was insulated with a large cardboard box which contained the rectangular area and a removable glass window has been used. The inner box having volume (52.5×24×36) cm covered on both sides with aluminum foil. A metal tray painted black. This experiment was done on temperature ranging from 65 to 75 °C.

The specific aims of this research are:

- design and construct a solar milk pasteurizer;
- determine the average quantity of the solar-pasteurized milk per day;
- analysis the thermal system of the solar milk pasteurizer.

MATERIALS AND METHODS

A solar thermal collector system had been constructed and evaluated in Department of Agricultural Engineering, Faculty of Agriculture, Ain Shams University, Shoubra El-Kheima, Egypt (Latitude 30° 02′ N, Longitude 31° 21′ E). The solar collector system works as a solar milk pasteurizer. It collects the heat from the solar radiation and gives it to the working fluid (milk) to achieve the overall goal of this study as presented in Fig. (1).

The technical specifications of the system, procedures, and experiments can be explained as follows:

The milk:

Fresh whole cow's milk (~ 3.5 % fat and 8.56 % SNF).

The thermal solar collector:

It is a flat plate collector, it has a surface area of 1.2 m^2 and consisted of five components; absorber plate, milk passage, insulation material, cover, and case. The absorber is formed from an aluminum sheet (1.2 m x 1.0 m and 1.6 mm), was painted with matt black paint in order to absorb the maximum amount of the incident solar energy. The working fluid tube (milk passage) was formed from tube with inner diameter of about 11 mm and thickness of about 1.0 mm. The pipe was shaped as a serpentine type and consisted of 10 horizontal tubes. The tubes are arranged at equidistant of about 10 cm and attached to the upper surface of the absorber plate, also this pipe was painted matt black. A single clear glass cover has a 6 *mm* thick was placed at above of the collector to cover the collector. The collector case was made from wood 25 mm thick, and 10 cm deep, the bottom of casing is backed with a plate (2.0 mm thick) of wood, and sides of the collector casing were also painted matt black. A 50 mm of wool glass was placed at the lower surface of the absorber plate to reduce the heat losses from the collector.

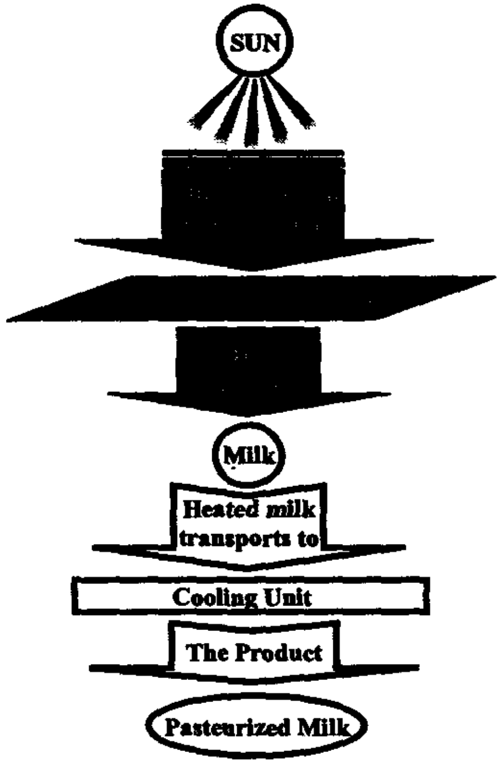

Fig. (1): Schematic diagram to produce pasteurized milk by the thermal utility of the solar energy.

The fresh-milk tank:

The fresh-milk tank is a plastic tank, has a capacity of 20 liters. It is insulated by a 50 mm glass wool.

The cooling unit:

The cooling unit is a heat exchanger of the shell and tube type. It consists of three components; ice shell, milk tube and insulation. An insulated large box (the shell) contains the ice which required for cooling the heated milk that flows inside a bundle of tubes which allows the heat to transfer from the milk to ice. The flow of milk inside the bundle tube is controlled by adjusting the delivery valve in order to achieve the required cooling temperature (about 4 – 8 °C). The milk tube has 3.8 m length with 9 mm inner diameter and 1.0 mm thick was shaped as a serpentine type in two parallel layers, 4 passages in each layer which arranged at equidistant of 10 cm, the distance between the two layers was, also, 10 cm. A galvanized steel box (15 x 36 x 45 cm) is used as ice shell, the top of the ice shell is removable in order to fill the shell with ice. A 25 mm wool glass is placed around the ice shell to insulate it, and the insulated shell is placed into a box of foam.

Temperature measurement instrument:

A digital thermometer (Model: DM6802A$^+$ / 2 ports; Accuracy: 1 °C; Thermocouple probe: type "K") is used to measure the temperature at certain points of the system.

The solar collector orientation:

The solar collector was faced to south, and tilted at 31° (Latitude of location), **William and Raymond (1985).**

The procedures and the designed system:

The ability of milk pasteurization by solar energy has been tested at pasteurization temperatures of 63 and 72°C (the temperatures 65 and 74°C are used practically instead of the temperatures 63 and 72°C, respectively, in order to verify reaching the pasteurization temperature, **Gaafar (2001)** by using the following constructed system that is shown in Figs (2 and 3). Fig. (4) shows the path of the milk through the system where milk was moving from the tank into the solar collector by gravity, the movement of milk within the system was controlled by valves at certain points in the system as shown in Fig. (2). The milk flew through serpentine pipe at a low flow rate to reach the temperature of pasteurization, then it flew out the solar collector to the holding tube when the pasteurization temperature was 63°C and remained for 30 minutes or it flew directly to the cooling unit, when the pasteurization temperature was 72°C.

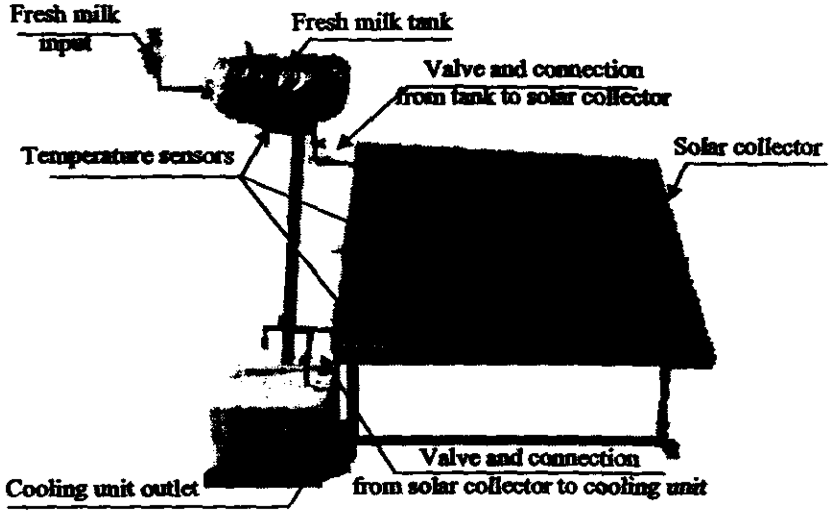

Fig. (2): Photograph of the constructed solar pasteurization system.

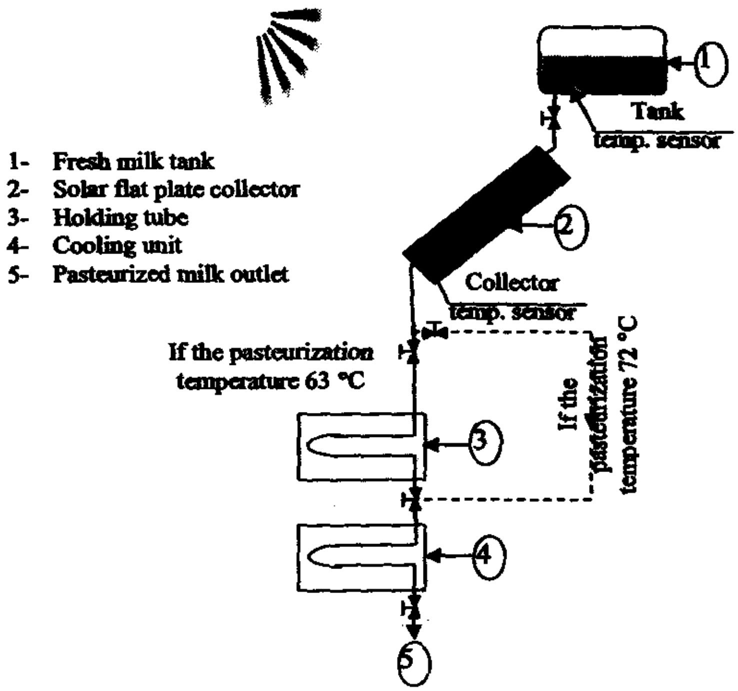

Fig. (3): Schematic of the solar pasteurization system.

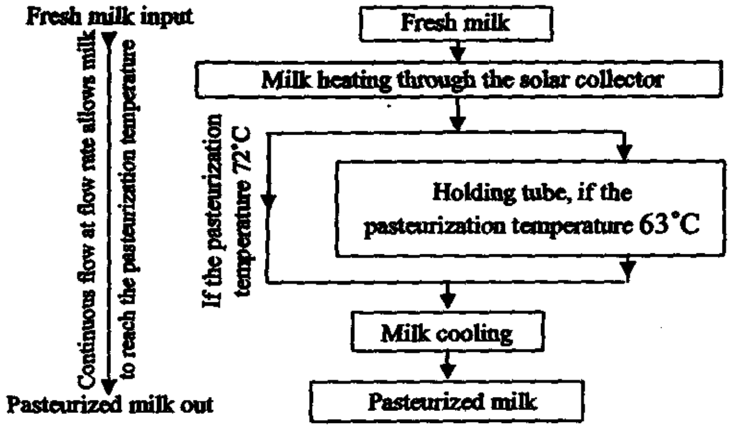

Fig. (4): Milk path through the solar pasteurization system.

Milk flow rate:

The milk flow rate "q" through the collector which allows milk to reach the pasteurization temperature was calculated by the following equation and then it was measured and verified practically.

$$q = AV \times 10^3$$
$$= \frac{\pi D^2}{4} \cdot \frac{L}{t} \times 10^3$$

where:

q: required milk flow rate, (*l*/min), related to the day time and pasteurization temperature;

A: section area of milk tube, (m^2);

V: milk flow velocity, (m/min);

D: tube inner diameter, (0.011 m);

L: tube length, (12.5 m);

t: required time to reach the pasteurization temperature (min), resulting from the following test.

Required time for reaching the pasteurization temperature:

The required time to reach pasteurization temperature, has measured by filling the serpentine pipe of the collector by batch fresh milk every 30 minutes, and measuring of the average milk temperature inside the collector every one minute up to 63 and 72 °C then the required time is recorded. This experiment is repeated at different conditions of weather and solar radiation, from 10 AM to 3 PM on 9, 12, 13 and 28 September, 1, 3 and 22 October and 5, 9 and 26 November 2009.

The daily quantity of solar-pasteurized milk:

The milk flow rate was estimated every 30 minutes due to the average effective of solar radiation. The quantity of milk which is applicable to solar-pasteurizing every 30 minutes at a certain pasteurization temperature was determined by multiplying the flow rate "q" by 30, as in the following equation:

$$q_b = q \times 30$$

where:

q_b: quantity of milk per batch (during 30 min), (*l*).

The daily quantity of pasteurized milk "q_{day}" was calculated by summing the quantities "q_b" for each pasteurization temperature during the periods of sunshine (from 10 AM to 3 PM), as following:

$$q_{day} = \sum_{i=1}^{n} q_b(i)$$

where:

n: the total number of batches per day;

q_{day}: the quantity of solar-pasteurized milk per day.

Milk path cleaning:

The heating of milk, leads to deposition for solids of milk on the sides of milk path. Therefore, the system should be cleaned at the end of each working day by filling the tank with water and little a liquid soap and pumped it to pass through the system. After that, the system should be washed with water several times.

Solar radiation data:

The values of solar radiation on horizontal surface (I_h) were obtained from Arid Land Research Institute, Faculty of Agriculture, Ain Shams University, Shubra El-Kheima. To determine the tilted solar radiation (R) on solar collector, the following equation, **William and Raymond (1985)**, was used:

$$R = I_h \sin(\alpha + \beta) / \sin(\alpha)$$

where:

$$\alpha = \sin^{-1}(\sin\delta \sin\Phi + \cos\delta \cos\omega \cos\Phi)$$

$$\delta = 23.45 \sin[360 (284 + n) / 365]$$

$$\omega = 15\,(t_s - 12)$$

where:

R: solar radiation incident on the tilted surface of solar collector, (W/m^2);

I_h: solar radiation incident on horizontal surface (the given), (W/m^2);

α: solar altitude angle;

β: the tilt angle of solar collector, (31°);

δ: solar declination angle;

ω: the hour angle;

Φ: latitude angle of the location, (30.08°);

n: day number of year;

t_s: solar time.

Thermal performance of the system:

The overall thermal efficiency of the solar collector is considered the basic parameter to evaluate the system thermal performance. It is defined as the ratio of the useful heat energy to the available solar energy on the collector aperture. So the thermal performance can be calculated using the following equations **(Kalogirou 2004 and ASHRAE 2005)** as follows:

$$Q = R \cdot Ac$$

where:

Q: available solar energy on the collector aperture, (W);

R: solar radiation incident on the tilted surface of solar collector, (W/m^2);

A_c: surface area of solar collector, (1.2 m^2).

The useful heat gain (Q_u) is equaled by:

$$Q_u = m\, C_p\, (T_{fo} - T_{fi}),\ \text{Watt}$$

where:

m: mass flow rate of milk through solar collector, (kg/s);

C_p: specific heat of milk, (3930 J/kg °C), **Walstra et al. (1999)**;

T_{fo}: outlet milk temperature, (pasteurization temperature °C);

T_{fi}: inlet milk temperature, (°C).

The overall thermal efficiency (η_o) depends strongly upon the useful heat gain and the energy collected by the collector. The solar collector overall thermal efficiency can be found from the following equation:

$$\eta_o = \frac{Q_u}{Q} x100$$

RESULTS AND DISCUSSION

Required time to reach the pasteurization temperature:

Fig. (6) showed the average results of the experiments from 10 AM to 3 PM during September, October and November 2009. It is clear that the lowest time to reach the pasteurization temperature was at noon. However, the longest time was at morning and afternoon. The average minimum time to reach the pasteurization temperature of 63°C was 3 minutes at noon in September and the average maximum time was 19 minutes at afternoon in November to reach the pasteurization temperature of 72°C.

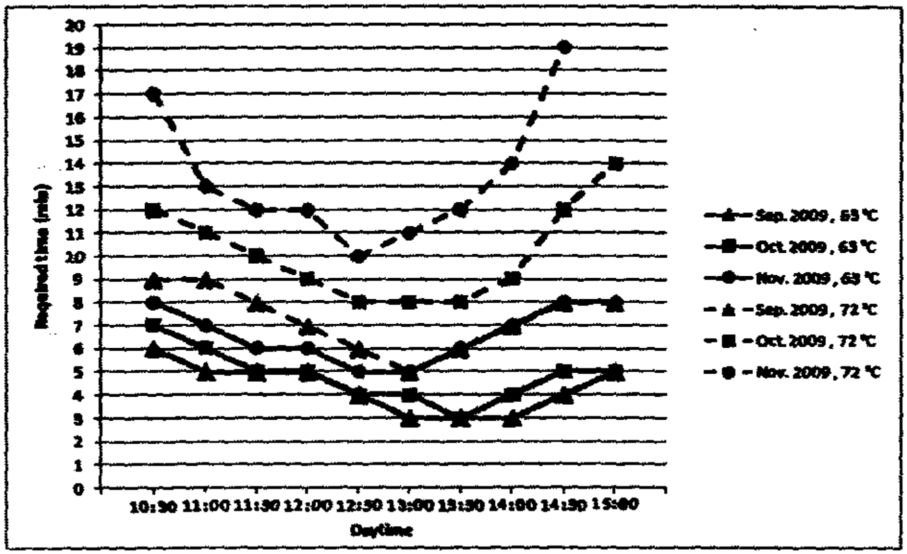

Fig. (6): Average required time to reach the pasteurization temperatures 63 and 72°C during September, October and November 2009.

Production rate of the solar-pasteurized milk:

Fig. (7) illustrated that the average quantity of the solar-pasteurized milk is inversely related to the required time for solar pasteurization. The average maximum quantity was 11.9 *l* at noon in September and October, while it was 7.1 *l* at noon on November when the pasteurization temperature was 63°C. The average minimum quantity was 1.9 *l* at 2 PM on November when the pasteurization temperature was 72°C.

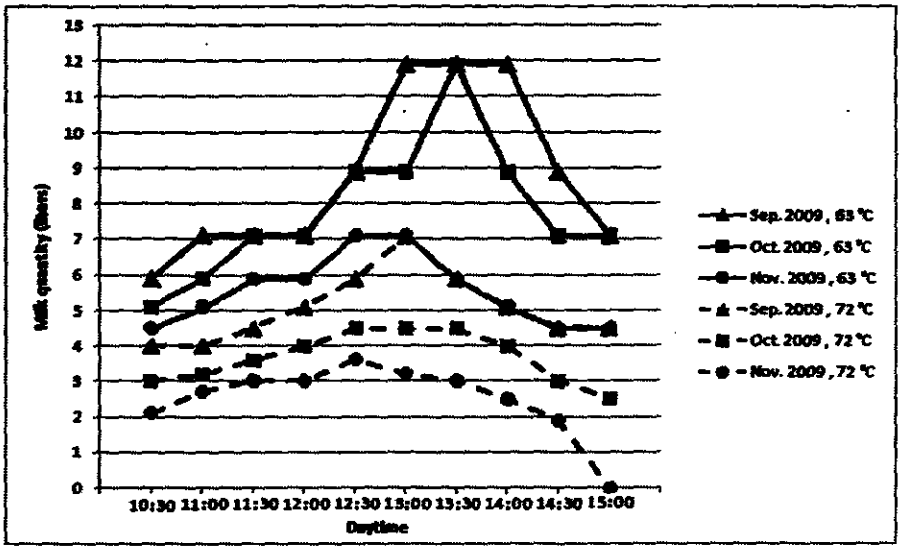

Fig. (7): Average quantity of solar-pasteurized milk at 63 and 72°C during September, October and November 2009.

Fig. (8) showed that the average daily quantity of solar-pasteurized milk in the months of September, October, and November were 87.9, 78.1 and 55.6 *l* /day, respectively, when the pasteurization temperature was 63°C. While they were 50.5, 36.6, and 25 *l* /day for the same period when the pasteurization temperature was 72°C.

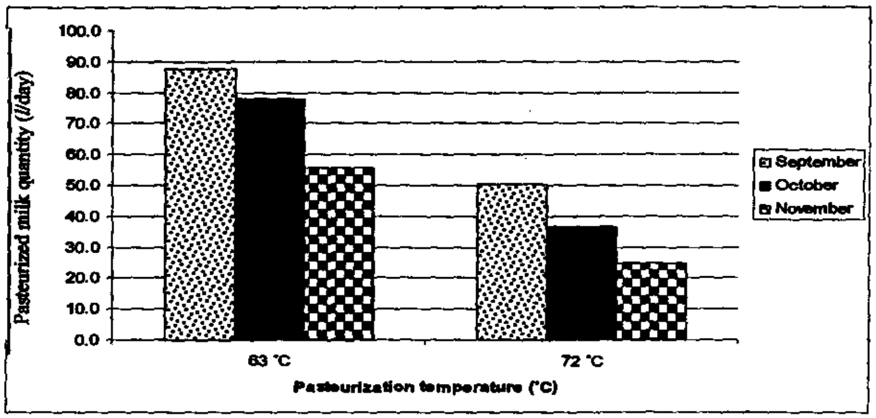

Fig. (8): The average daily quantity of solar-pasteurized milk during September, October and November 2009.

It is clear that the change in intensity of solar radiation had a direct impact on the quantity of solar-pasteurized milk.

September, October and November, this period of year that is the autumn months, so it has average values of solar intensity and sunshine hours of the year. Consequently, the average production during the three months (September, October and November) can be used as an average annual predicted production, therefore, the annual average daily quantity of solar-pasteurized milk by the constructed solar-pasteurizer is 73.9 *l* /day when the pasteurization temperature is 63°C, while it is 37.3 *l* /day when the pasteurization temperature is 72°C.

System thermal performance:

The average of the available solar energy per day during the experimental period was 8.3 kWh/day. The daily average useful heat that was gained by the milk during the experimental period was 3.4 kWh/day and 2.5 kWh/day when the pasteurization temperature was 63°C and 72°C, respectively, Fig. (9), showed the average overall thermal efficiency. It is obvious that the average lowest thermal efficiency was 31.3 % at 3 PM, while the maximum value was 54.1 % at noon when the pasteurization temperature was 63°C, while the average lowest thermal efficiency was 17.5 % at 3 PM, and the maximum value was 43 % at noon when the pasteurization temperature was 72°C.

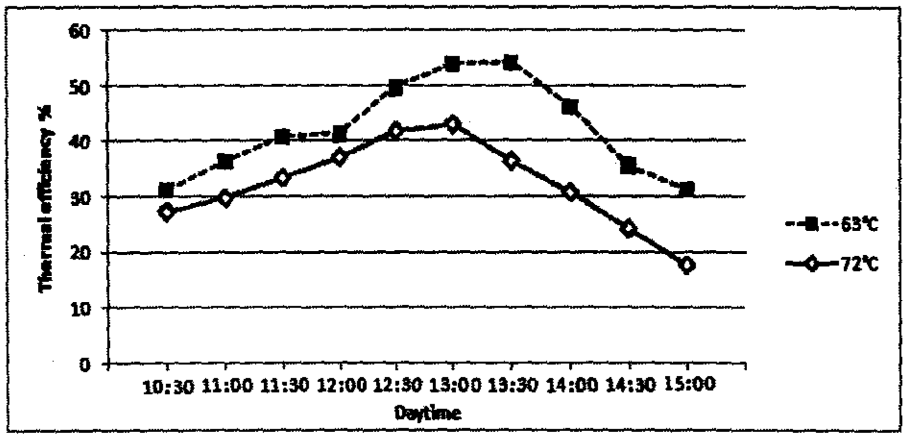

Fig. (9): Overall thermal performance of the solar thermal collector.

CONCLUSSION

This research aimed to apply solar energy for milk pasteurization. Liquid milk has been pasteurized by using a 1.2 m^2 solar flat plate collector. The pasteurization temperatures of 63 and 72 °C were used.

The obtained results indicated that the average daily quantity of solar-pasteurized milk in the months of September, October, and November were 87.9, 78.1 and 55.6 *l* /day, respectively, when the pasteurization temperature was 63°C. While they were 50.5, 36.6, and 25 *l* /day for the same period when the pasteurization temperature was 72°C.

The conclusions of this study are as follows:

1. The solar milk pasteurizer attained pasteurization temperatures in 3 to 19 minutes depending on the average solar intensity;
2. The average yearly quantity of solar-pasteurized milk by the constructed solar-pasteurizer is 27.5 ton/year when the pasteurization temperature is 63 °C, while it is 13.8 ton/year when the pasteurization temperature is 72 °C.

It can be recommended that:

1- Pasteurization of milk by this constructed system at 63°C during the period from 10 AM to 3 PM.

2- Design the system with features of automatic control.

3- Use of such designed system to pasteurize water and juices.

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<u>الملخص العربى</u>

الإستفادة من الطاقة الشمسية في بسترة الألبان

مبارك محمد مصطفى[1]، مصطفى فهيم عبد السلام[2]، محمود أحمد النونو[2]، محمد فتحى عطيه[3]

يعتبر اللبن من المكونات الأساسية والهامة في غذاء الإنسان في مختلف مراحل حياته. ولما كان اللبن يمثل بيئة ممتازة لنمو الميكروبات الضارة بالانسان فإنه يستلزم القضاء عليها، ويتم ذلك بمعاملة اللبن حرارياً عند درجات حرارة محددة ولفترات زمنية محددة، وهذه العملية تسمى بالبسترة. وتلك العملية تستهلك طاقة، مما يجعلها تمثل عبئا على صغار منتجي الألبان والمزارعين في القرى، كما انه احيانا قد لا تتوفر مصادر للطاقة كالكهرباء أو الغاز تلك المصادر اللازمة لإجراء البسترة. ومن هنا كان التفكير فى إيجاد بديل أرخص من مصادر الطاقة التقليدية ليستخدم فى البسترة. ولما تمثله الطاقة الشمسية من مصدر متاح بدون قيود، نظيف ورخيص، علاوة على وجود مصر ضمن دول الحزام الشمسى. فقد ادى التفكير الى استخدام الطاقة الشمسية كمصدر للطاقة الحرارية اللازمة فى عملية بسترة الالبان.

تهدف هذه الدراسة إلى تصميم وتصنيع نظام لبسترة الألبان يعتمد بشكل أساسى على الطاقة الشمسية كمصدر للطاقة الحرارية اللازمة للبسترة. وقد تم انشاء مجمع شمسي من النوع ذو اللوح الماص، مساحة سطح المجمع ١,٢ م٢ ليعمل كسخان ومبادل حراري لبسترة اللبن وكذلك تصميم نظام لبسترة اللبن باستخدام المجمع الشمسى. وكانت درجات الحرارة المستخدمة لبسترة اللبن هى ٦٣ ، ٧٢ °م. وقد أجريت التجارب خلال الشهور سبتمبر، اكتوبر، ونوفمبر من عام ٢٠٠٩.

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وقد تم أيضاً:

- تقدير الكمية التي يمكن إنتاجها يومياً من اللبن المبستر بالطاقة الشمسية.
- تحليل الأداء الحراري للنظام.

وقد أظهرت النتائج ما يلي:

١- وصل اللبن إلى درجة حرارة البسترة في زمن استغرق من ٣ إلى ١٩ دقيقة على حسب درجة حرارة البسترة المطبقة وشدة الإشعاع الشمسي.

٢- بلغ متوسط أقصي كمية من اللبن المبستر المنتجة يومياً باستخدام الطاقة الشمسية ٧٣,٩ لتر عند ٦٣ °م ، بينما بلغ متوسط أدني كمية يومياً ٣٧,٣ لتر عند ٧٢ °م.

ويمكن أن يوصى بما يلي:

١- بسترة اللبن باستخدام هذا النظام على ٦٣ ° م خلال الفترة من ١٠ صباحاً إلى ٣ مساءاً.
٢- تصميم الجهاز وتزويده بنظام للتحكم الآلي.
٣- إستخدام الجهاز لبسترة الماء والعصائر.