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Design and evaluation of indirect incubator to manfacture yoghurt using solar-energy

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Abstract

This paper presents a design and a performance comparison between three temperatures 38,40 and 42 ^{O}C for manufacture yoghurt by a solar-energy (SE) to obtain suitable temperature for best quality product. Thermal analysis was performed without load to tests the effect of high air mass flow on incubator and the collector efficiency and effectiveness under three various air mass flow rate (0.031, 0.046 and 0.062 kg/s). The resultant yoghurt samples were tested to compared with the other yoghurt produced by an electrical incubator. The analysis of results showed that the produced yoghurt at 42 ^{O}C was a high quality one compared to those with others temperature. It noticed that the yoghurt produced by (SE) had a high quality compared to electrical energy. The obtained data cleared that the percentage of collector efficiency were ranged from 40.24 to 86.76 , 28.05 to 68.19 and 20.20 to 43.55 while the effectiveness were ranged from 26.83 to 48.48, 25.30 to 41.46 and 31.25 to 39.84 in addition to that the percentages of incubator efficiency ranged from 9.66 to 37.05, 16.11 to 58.64 and 29.92 to 61.53 while the effectiveness ranged from 35.34 to 54.62, 28.44 to 57.14 and 24.82 to 70.96 for exhausted fan speed 1.5, 2.2 and 3 m/s respectively. Collector efficiency increased while incubator decreased with increase in the air flow rate. The effectiveness increased for collector and incubator by exceed air flow rate. Finally an economic evaluation was calculated using the criterion of payback period which is found very small 1.34 years compared to the life of the incubator 25 years.

Keywords: Yoghurt, Solar-energy, Collector, Incubator, Efficiency, Effectiveness

1.Introduction

Ozcan-Yilsay (2007) [18] reported that yoghurt is a functional dairy product unique for its nutritional, therapeutic and probiotic effects. It is produced by fermentation of milk with the thermophilic homofermentative lactic acid bacteria *Streptococcus thermophilus* and *Lactobacillus delbrueckii* ssp. *bulgaricus*.

Blades (2000) [6] and Trepel (2004) [21] highlighted an increasing interest has developed in foods that contribute to a positive effect on health for their nutritional value. Among these functional foods, much attention has been focused on probiotic products and food containing dietary fiber.

Panagiotis and Constatnina (2014) [19] found that fermentation Process is the most important stage of yoghurt manufacture. During this stage, the yoghurt curd is formed, and its textural characteristics and distinct flavor are developed anaerobic bacteria and its optimum growth temperature is 40–44 °C.

Nowadays, Scientists in different countries are trying to find the best way to collect and store solar energy and exploit it in many industrial applications. solar energy is an important inexhaustible source of energy as cheap, non-pollutantin and environmentally friendly compared to higher prices and shortage of fossil fuels.

Ghoniem and Gamea (2014) [10] said that the power from the sun intercepted by the earth is approximately 1.8 × 1011 Mw which is many thousands of times larger than the present consumption rate of all commercial energy sources on earth.

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Boughali et al. (2009) [7] carried out some experiments on an indirect active hybrid solar–electrical dryer was constructed and experimentally tested in the town of Ouargla. As a result air in the cabinet dryer with different airflow rate is better to use low airflow rates for drying process.

Matuam et al.(2015) [16] carried out some experiments on thermal performance of dryer in the case of vertical countercurrent airflow according to the drying principle. The analysis of results showed that dryer efficiency decreases to 34%, 25% and 22% with increase in the drying temperature at 40°C, 50°C and 60°C respectively.

Asaadrehman (2010) [5] said that the solar collector insalled southward and tilts at an angle of 15°, plus to the latitude value in winter, while it Subtract in summer to be Sun rays vertical on the surface of the complex. He studied also the equations needed to design and calculate both the Solar collector area and incubator efficiency.

Imants (2010) [11] found that the value and the intensity of solar insolation depend on the latitude and weather conditions of the place. They developed the collector efficiency and heat energy produced by using of computer program MS Excel. the results presented By the use of the computer program MS Excel it is simply to calculate technical parameters of the collector and the efficiency of collector dependent on the difference between the absorber and surrounding air temperature.

Alonge (2008) [3] carried out some experiments on two passive solar dryers which were direct and indirect type. experiment cleared that the direct passive solar dryer performed better than theindirect passive solar dryer.

Ghoniem et al (2014) [14] designed solar cooker made of locally available materials. The cooking time varied with the cooked food substances where it was an hour and forty minutes for cake mixtures ,two hours for meat. The cost analysis indicated that the yearly fixed cost (Fc) is high (58 L.E/year) but the hourly cost is low (0.056 L.E/hour).

The processes that take place during yoghurt manufacture with conventional industrial methods effect on the texture and flavor of the final products.

The research was conducted to produce yoghurt by a solar-energy under virus tempratue were 38,40 and 42 °C and compare the qulity of product by the other yourt prduce by an electrical incubator. Change tempratues of yourt manfacture were applied to determine the relation between increased of ambient air temperature and the qulity of product. The goal of this research is also to determine the efficiency and effectiveness of the Solar collector and incubator under three various air mass flow rate. The hightest value of collector and incubator efficiency and effectiveness will apper and accombiend with the best air mass flow rate.

To achieve this aim the following was carried out.

1. Analysis and testes yoghurt by a solar-energy and electrical energy.
2. Comparing between the qulity and flvour of product manfcture by solar-energy and electrical energy.
3. Calculated and comparing the efficiency and effectiveness of collector and incubator under various air mass flow rate by MS Excel.
4. pointing to the best way and temperature to produce yoghurt with hight qulity and flvour.
5. Calculate Payback period of the yoghurt solar–energy incubator.

2. Materials and methods

2.2. Materials

Experiments were carried out during the month of October, 2018 in Zagazig City, Sharkia governorate, Egypt. (longitude (Φ) =34° 30’ 00” N and latitude (λ) =30° 31’ 00” E). The incubation of yougrt was investigated in the indirect forced convection solar–electrical constructed and installed at a the roof of house in Zagazig City of Sharkia governorate, Egypt. The experiments started at 8:00 am and terminated at 5:00 pm. The ambient air speed where ranged from 0.7 to 3.2 m/s while the relative humidety ranged from 31% to 62% whole duration of the experiment. Solar collector and - incubator was placed on a raised in iron installation frame far from the shade of trees or buildings during the whole duration of the experiment.

The main components of each incubation yoghurt system are:

*Flat plate solar collector:*The solar air collector has an area of 1.5 m2 is inclined at an angle of 19° 30’ 00” N (latitude of Zagazig city) with the horizontal facing south all the time and use of sheet metal absorption zigzagging from galvanized sheet thickness 0.001 m and 55 o goffer angle and height of 0.05 m from the basises of plate and painted matte black not shiny to absorb most of the incident solar radiation. The top losses are minimized by placing a glass cover of 0.005 m thickness over the top of the metal galvanized sheets is used as a sides and an insulation layer of fiber glasses sandwiched between two parallel galvanized metal sheets is used as sides and back insulator. The solar air collector fabricated with a galvanized iron box with insulated fiber glasses thickness 0.0 25 m from the sides of the collector and 0.05 m from the bottom of collector walls of dimensions (1.5 × 1 × 0.30) m (height, width and depth).There is a distance of 0.20 m as air gap between the glasses cover and the absorbing black metal plate zigzagging. A sheet formed as half-circle placed to direct the air at the absorption plate putting at the beginning of the collector and so that the air was drawn under the glass sheet and the absorber.Ther is one opening in the front of collector to enter ambient air and four openings for exhusted air from collector and connect to incubator by four plastic tubes isolated.

Solar yougrt - incubator: The incubator cabinet yoghurt fabricated with in galvanized iron box with insulated fiber glasses walls of dimension (1.5 × 0.50 × 1) m (height, width and depth) The incubator cabinet yoghurt galvanized iron box insulated with fiber glasses thickness 0.025 m from the sides of the collector and 0.05 m from the top and the bottom of cabinet over the top of the metal galvanized sheets is used as a sides and an insulation layer of fiber glasses sandwiched between two parallel galvanized metal sheets is used as sides and back insulator and the incubator cabinet including four perforated wire mesh self and duple door easy to open and closed to putting the product. incubator cabinet provied with two electrical exhusted fan with diameter 0.15 m model MH-15G power in put 16 watt, running at 1560 rpm/minute and air flow rate at 1.5,2.2 and 3 m3/s was manually controlled by electrical resistance to change air velocity.

Iron installation frame: Iron fram used to putting solar collector and incubator on it but the fram allow to a solar collector rotating around the axis of its fixation to change the angle of inclination as aseason and the city location.

Raw materials

1-Fresh mixed (1:1) cow's and buffaloes' milk (4% fat) was obtained from a private farm. Direct Vat Starter (DVS) yoghurt culture obtained from CHr. Hansen Laboratory Copenhagen, Denmark under commercial name type (DVS-YC-350) containing *Streptococcus thermophilus* and *Lactobacillus delbrueckii* ssp *bulgaricus* was used in the fementation processs.

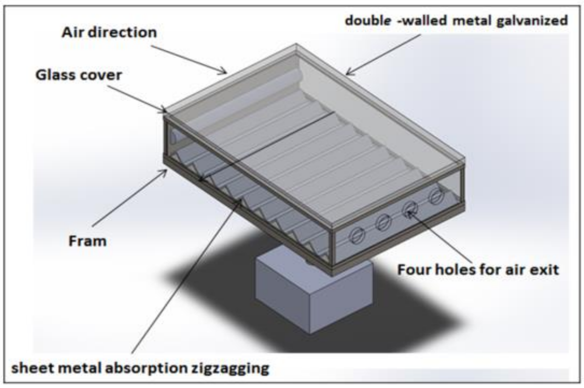

Figure 1. Solar collector component

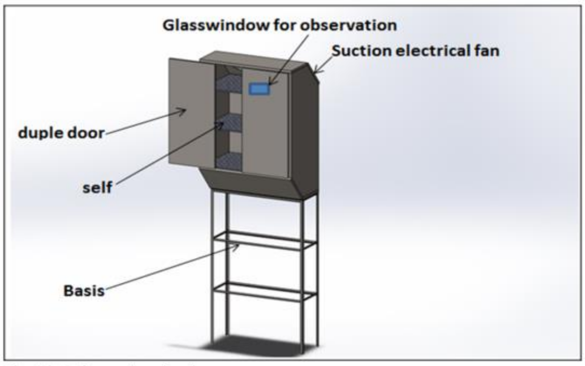

Figure 2. Solar yoghurt incubator component.

2.2.Methdos

The ambent air enter the solar collector through the front opening and the air wave directs air to the absorber metal plate which heated after absorbing the solar energy and transferred the heat to the ambient air and this air absorbing the heat and its volume extension and raised to the top of the solar collector because of decreasing its density. The heated air forced by suction strength of electrical ehxhusted fan to the incubator cabinet of yoghurt through four plastic tube. The heated air by solar radiation controlled thermostatically by a thermostat by operation or turning off ehxhusted fan. A themal performanc analysis to the the sloar collector and incubator with out load under different air speed were 1.5, 2.2 and 3 m/s then the collected data were analezed by MS Excel to calculated the efficiency and effectiveness of collector and incubator under various air mass flow rate then comparison between the efficiency and effectiveness of collector and incubator for pointing to the best air mass flow rate.

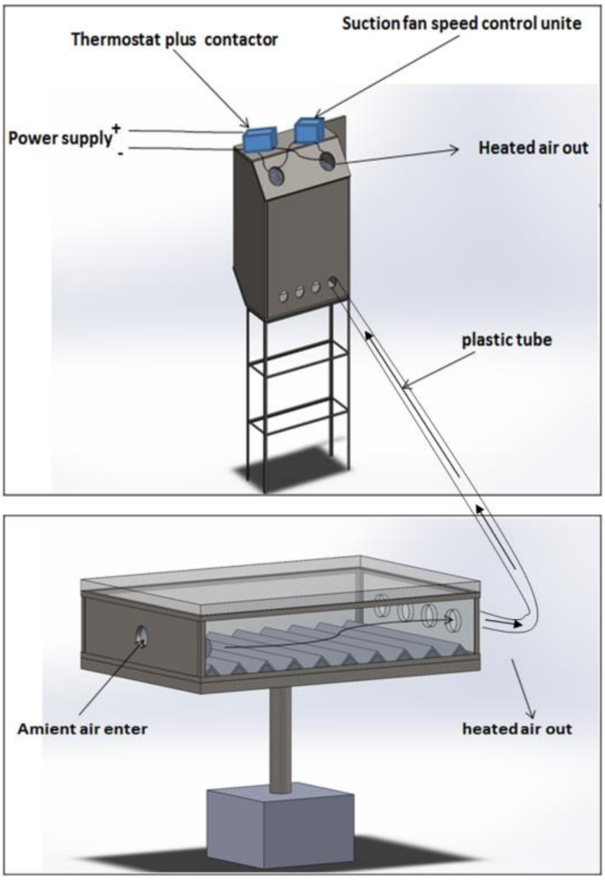

Figure 3. Solar yoghurt manfacture system.

Measuring Instruments Data.

"Watchdog" weather station model 900 ET. Was used for monitoring solar radiation (1 ~1250 W/m2) with accuracy of ± 5%.

Digital thermometer Model (TPM -10) series hand held Instrument. With a thermocouple was used for monitoring temperature with accuracy of ± 1 ºC and at range (-50 ºC ~ 110 ºC) by reading liquid crystal display (LCD) and operating in environment Humidity: range 5%~80%.

Digital Anemometer Model (GM816) series hand held Instrument. Used for measuring wind speed & temperature by reading liquid crystal display. Wind speed range (0 ~30 m/s) while wind temperature range (-10 ~45 ºC) with accuracy of ± 5% and ± 2% respectively.

Digital hygrometer-thermometer Model (ETI 810-155) series hand held Instrument. With a thermocouple was used for monitoring relative humidity at range (20 - 99 %) with accuracy of ± 5% and temperature at range: -0 ºC to +49 ºC in - -49 ºC to + 69 ºC out.

Mathematical modeling of solar collector& incubator yoghurt system.

1-Solar collector thermal performance: Thermal performance of solar collector was evaluated by dividing

Quantity of heat which is converted by the absorber to the collector area and calculated by the following equation.

$$Qconv._C = m\,Cp\,(T_{c\ out} - T_{c\ in}) / Ac \longrightarrow (1)$$

Where:

$Qconv._C$ = converted heat (W/m^2)
Cp = specific heat of air 1007 (J/kg.^{o}c)
m = mass flow rate of air (kg/s)
$T_{c\ out}$ = outlet air collector temperatures (^{o}c)
$T_{c\ in}$ = inlet air collector temperatures (^{o}c)
Ac = absorbent area (m^2)

$$Qgain._I = m\,Cp\,(T_I\ in - T_I\ out) \longrightarrow (2)$$

Where:

$Qgain._I$ = converted heat (W/m2)
Cp = specific heat of air 1007 (J/kg.^{o}c)
m = mass flow rate of air (kg/s)
T_I in = outlet air incubator temperature (^{o}c)
T_I out = inlet air temperature (^{o}c)

Collector efficiency (%$_n$): collector efficiency is defined as the ratio of energy output of the collector to energy input (R. Ac) to the collector (J) and is calculated from the following mathematical formula.

$$\%\eta = \frac{m.\,Cp\,.\,\Delta T}{R.\,Ac} \times 100 \longrightarrow (3)$$

R = solar radiation (W/m2)

Incubator efficiency (%$_n$): incubator efficiency is defined as the ratio of energy output from collector to energy gained by incubator and calculated using the following equations.

$$\%\eta = \frac{Qgain._I}{Qconv._C\,.A_C} \times 100 \longrightarrow (4)$$

Collector effectiveness (% EC):- Collector effectiveness **in the following form:**

$$\%\,E_C = \frac{(T_{I\,in} - T_{I\,out})}{(Tc_{\,out} - T_{I\,in})} \times 100 \longrightarrow (5)$$

Incubator effectiveness (%E_I):- Incubator effectiveness was simplified as per the following relationship.

$$\% E_I = \frac{(Tc_{in} - T_{amb})}{(Tc_{out} - T_{amb})} \times 100 \quad (6)$$

***Manufactur of yoghurt*:**

Yoghurt samples were prepared according to the procedure described by (Tamime and Robinson, 1983) [20], the milk was heated at 90^{0}C in a water bath for 10 min., then cooled to 38-40 and 42 ^{0}C . All Samples inoculated with 3% (v/v) of DVS mother culture followed by incubation until pH reached to 4.6 - 4.7 .

For each parameter, samples were analyzed in three replicates. The Total solids content, protein, fat content and The percentage of Titratable acidity contents were determined according to the method as described by (AOAC, 2012) [4]. The pH of samples was determined using pocket pH meter (IQ Scientific USA, Model IQ 125). Total bacterial counts and coliforms were determined according to standard procedures [15].

*Sensory evaluation***:** The organoleptic properties included flavor 60 points; body and texture 30 points and appearance was given score of 10 points [9,17]. The organoleptic evaluations was done by 10 of staff members.

Rheological properties: Curd tension was determined according to **(**Chandrasekhara *et al.*, 1957) [8], as described by (Abdel El-salam *et al.*,1991) [1]**.**

Payback analysis: - Based on the climatic conditions in Zagazig City which allow using the yoghurt solar- incubator system almost all the year days (365 days). The costs and the main economic parameters based on the economic situation in Egypt are shown in Table (1).

Using this data, the payback period was calculated using the formula below

$$\text{Payback period} = \frac{\text{Initial Investment}}{\text{Annual Net Undiscounted Benefits}} \quad (7)$$

The payback period is determined as the time required for the investment cost to equal the return.

Table 1. Payback period of the solar yoghurt incubator.

Cost of yoghurt collector & incubator	10000 L.E
Capacity of incubator	1. 16 kg
Depreciation	2. 1000 L.E
Life of incubator	25 years
Cost of maintenance	500 L.E
Labor cost (Heating & starter) 15 × 365 year	5475 L.E
Employment	18000 L.E
Cost of electrical consumption, L.E /year	21.9 L.E
Cost of raw milk 12 × 16 × 365	70080 L.E
Total cost	95076.9 L.E
Total income 1.5 × 160 × 365	87600
Net income	7476.9
Note 1US Dollar ≈ 18 L.E.	

3.Results and disscussion

Behavior of solar–electrical incubator without load: Measurements for 3 days in summer season (4, 5 and 6/10/2018) were made in order to study the behavior of our yoghurt incubator.Information on the ambient air temperature, air Speed, humidity of ambient Air and solar radiation is important when designing and evaluation a thermal performance of the solar collector& incubator yoghurt system.The outlet air temperature of the solar collector which inlet of the incubator is an important parameter for incuation, it varies in the same direction as the increased of solar radiation on this collector and by decreasing drying air velocity (Figs. 4–6).

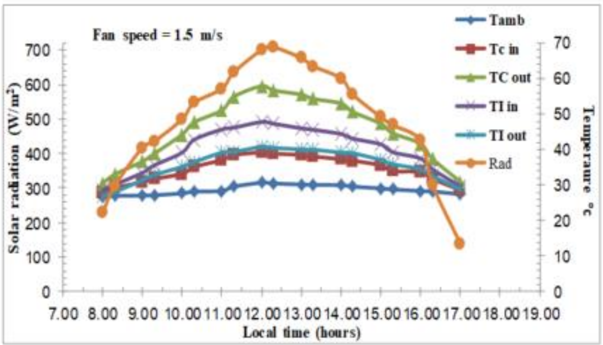

Figure 4. Solar radiation and temperature variation of different elements of the collector on 4/10/2018

The experiments showed that during the peak afternoon hours an average rise of air temperature between the input and output of the collector was

equal maximum to 13.7, 14 and 18 ^{o}c while it varying between (2.4~18.7^{o}c), (2.4~18.3^{o}c) and (1.7~23.7^{o}c) with an average air velocity of 2,2.2 and 3 m/s respectively. It is observed that the outlet air temperature of the solar collector increased above 50^{o}c. the losses of the solar collector outlet air arrive to 17.44, 14.84 and 13.91% by air velocity of 1.5 ,2.2 and 3 m/s as they decreased by increased air velocity.

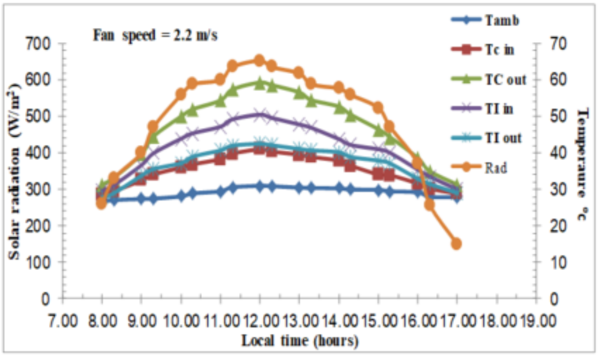

Figure 5. Solar radiation and temperature variation of different elements of the collector on 5/10/2018**.**

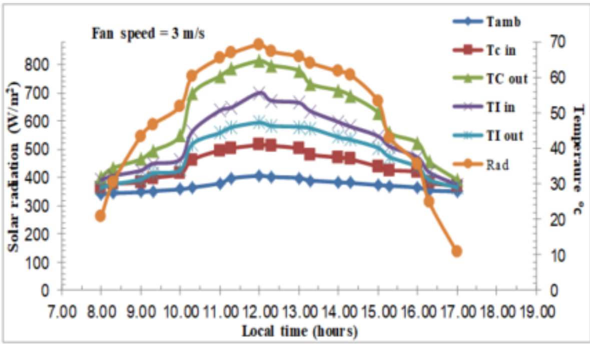

Figure 6. Solar radiation and temperature variation of different elements of the collector on 6/10/2018.

Collector efficiency ($\%_n$): It can be seen from (Fig. 7) that the daily collector efficiencies ranged between 20.2 and 43.56 at 0.0314 kg/s, 28.05 and 68.19 at 0.0461 kg/s and 38.09 and 86.76 at 0.0628 kg/s respectively. So the collector efficiency at air mass flow rate 0.0628 kg/s is better comparatively with other flow rates. We observed that, collector efficiency increases with solar radiation increase until a limit where the efficiency tends to come down beyond this value

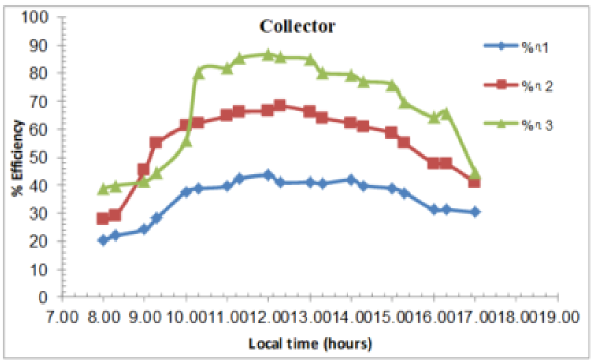

Figure 7. Daily collector efficiency various flow rates and local time.

It is generally know that the collector efficiency increases with air flow increase until a limit of air masse flow rate at 0.0628 kg/s where the efficiency tends to perfect at this value [12].

At 0.056 kg/ s where the efficiency tends to saturate beyond. Due to the

linear relationship between the velocity of air masse flow rate and the passage of local time noted that collector efficiency rises, rapidly at hight velocities 3 m/s and nearly constant above this value.

Kutscher et al. 1993 [13] noted that efficiency is nearly constant for approach velocities greater than 5 m/s. Our results are generally in agreement with earlier studies.

Incubator efficiency ($\%_n$): Fig. (8) Pointing to the the daily incubator efficiencies ranged between 29.93 and 61.53 at 0.0314 kg/s, 23.57 and 64.29 at 0.0461 kg/s and 20.56 and 75.86 at 0.0628 kg/s respectively. So the incubator efficiency at air mass flow rate 0.0461 kg/s is better comparatively with other flow rates. It is noticed that when air flow rates of the incubator increased from0.0461 kg/s to 0.0628 kg/s the percent of the incubator efficiency decreased, slow rate permeation to get the greatest amount of energy entering the incubator. As there is a seasonal variation in the climatic parameters of ambient air and the solar radiation so that the efficiency of our system is not uniform. The daily efficiencies of the incubator are often in range from 25 to 52%.

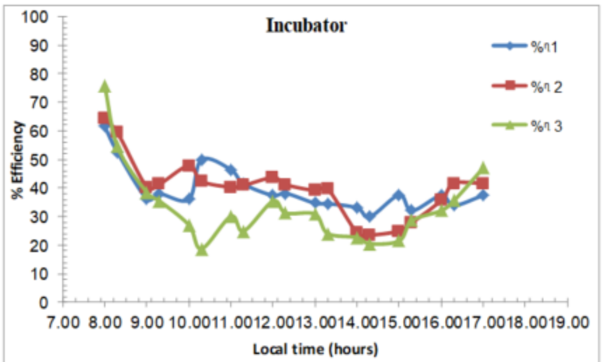

Figure 8: Daily collector efficiency various flow rates and local time.

Collector effectiveness (% EC). The thermal collector effectiveness presented in fig. (9). The maximum and the minimum of collector effectiveness were from 31.25% to 39.84%, 25.30% to 41.46 and 25.36% to 48.48% at air speed 1.5 , 2.2 and 3 m/s respectively. Solar collector effectiveness at different solar time starting 8.00 AM to 5.00 PM depend on the rise in air temperature between inlet and outlet (ΔT) starts small in the morning and gradually increases until it reached maximum at one P.M. then decreased gradually until sunset. Effectiveness for collector ranged from 25.30% to 48.48%.the effectiveness of collector is the best at fan speed 2 m/s compering with the others rates.

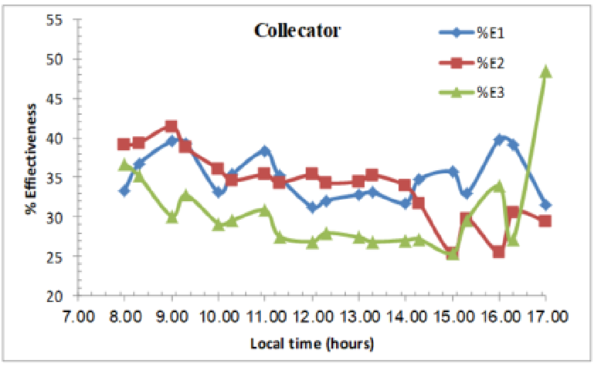

Figure 9. Daily collector effectiveness various flow rates and local time.

Incubator effectiveness (%EI): Fig.(10) showed that the effectiveness of incubator which are ranged from 35.34% to 54.62%, 28.24% to 57.14% and 24.82% to 70.96% for air speed rats 1.5, 2.2 and 3 m/s respectively.it observed that the effectiveness of air speed is the perfect almost time.

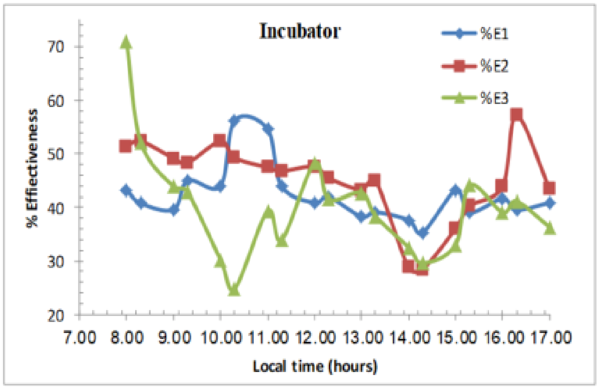

Figure 10. Daily incubator effectiveness various flow rates and local time.

Payback analysis: The payback period is calculated as the time required for the investment cost to equal the return. In our case the payback period is very small (1.34 years) compared to the life of the dryer (25 years), so the dryer will dry product free of cost for almost its entire life period.

$$\text{Payback period} = \frac{10000}{7476.9} = 1.34 \text{ years.}$$

Table (2) shows the effect of using solar energy incubator on the behavior of yoghurt starter culture during fermentation. Significant differences ($P<0.05$) were found in the pH of yoghurt with the different degree of heat incubation of using solar energy incubator. These results can be explained the starter activity when we used solar energy incubator compared to using traditional electricity incubator. Also, using solar energy and electricity incubator affected by heat degree of incubation. The highest activity of yoghurt started recorded when using solar energy incubator and 42 ^{0}C . changes in the milk substrate by LAB during fermentation are attributed to fermentation temperature, ingredients added during manufacturing, fermentative action of the inoculated starter cultures and the secretion of nutritional and chemical substances by the microorganisms [2, 14].

Table 2. Microbiological properties and the changes in pH during the fermentation

Treatments	Traditional incubator			Solar energy Incubator		
	38^{0}C	40^{0}C	42^{0}C	38^{0}C	40^{0}C	42^{0}C
TC count	7.12	7.32	7.40	7.45	8.00	7.80
Coliforms	ND	ND	ND	ND	ND	ND
pH						
After 30 min. of incubation	6.00	5.90	5.70	5.90	5.90	5.70
After 60 min. of incubation	5.50	5.40	5.40	5.20	5.40	5.10
After 90 min. of incubation	5.30	5.20	5.00	5.00	5.20	4.80
After 120 min. of incubation	5.00	4.90	4.70	4.70	4.60	4.60
After 150 min. of incubation	4.70	4.60	4.60	4.60	4.60	4.60

The data which obtained from Table (3) indicated that no significant variation between all treatment. On the other hand noticed significant variation between treatments, using solar energy incubator in made yoghurt had T.C higher than traditional incubator. Using 42 ^{0}C by using solar energy incubator has the highest total count bacteria No coliform bacteria had detected in all treatments.

Table (4) indicates that using solar energy incubator in made yoghurt gained the highest significant ($P<0.05$) scores in flavour as compared to traditional incubator In addition, the heat treatment 42^{0}C gained the highest scores among the other.

Table 3. Chemical composition and curd tension of fresh yoghurt.

Treatments %	TRADITIONAL INCUBTOR			SOLAR ENERGY INCUBATOR		
	38^{0}C	40^{0}C	42^{0}C	38^{0}C	40^{0}C	42^{0}C
T.S%	13.65	14.70	15.40	14.70	14.80	15.80
Protein%	3.70	3.85	3.95	3.85	3.90	3.90
Fat%	4.60	4.60	4.70	4.70	4.70	4.75
Acidity%	0.76	0.80	0.80	0.78	0.82	0.80
TVFA content	1.15	1.18	1.18	1.18	1.22	1.20
Curd tension	40	50	50	41	52	55

Table 4. organoleptic properties of fresh yoghurt affected by heat treatment

Properties	TRADITIONAL INCUBTOR			SOLAR ENERGY INCUBATOR		
	38^{0}C	40^{0}C	42^{0}C	38^{0}C	40^{0}C	42^{0}C
Appearance (10)	10	9	9	10	10	10
Firmness (10)	9	9	9	10	10	10
Smoothness (10)	9	9	9	9	9	9
Wheying-off (10)	9	9	10	9	9	10
Flavour						
Acid (10)	8	9	8	9	10	10
Bitterness (10)	9	9	9	9	9	9
Flat (10)	9	9	9	10	9	10
Foreign (10)	9	9	9	8	9	9
Coocked (10)	9	9	9	9	9	9
Unclean (10)	9	9	9	9	9	9
Total (100)	90	90	91	92	93	95

Conclusions

- The average rise of air temperature between the input and output in the collector varying between (2.4~18.7^{o}c), (2.4~18.3^{o}c) and (1.7~23.7^{o}c) with an average air velocity of 1.5,2.2 and 3 m/s respectively.
- The daily collector efficiencies ranged between 20.2 and 43.56 at 0.0314 kg/s, 28.05 and 68.19 at 0.0461 kg/s and 38.09 and 86.76 at 0.0628 kg/s respectively.
- The daily incubator efficiencies ranged between 29.93 and 61.53 at 0.0314 kg/s, 23.57 and 64.29 at 0.0461 kg/s and 20.56 and 75.86 at 0.0628 kg/s respectively.
- The high efficiency of the solar collector was accompanied by air speed 3 m/s while incubator at speed 2.2 m/s
- The results cleared that the percentage of collector effectiveness ranged from 25.30 to 48.48 while the incubator effectiveness were ranged from 24.82% to 57% respectively.
- Using solar energy incubation yoghurt and 42^{0}C in made yoghurty recordef high quaulity and sensory properties comapred to other treatments.
- the payback period for is yourgt incubator were1.34 years.

Compliance with Ethics Requirements. Authors declare that they respect the journal's ethics requirements. Authors declare that they have no conflict of interest and all procedures involving human / or animal subjects (if exist) respect the specific regulation and standards.

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