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Designing,Fabricating and Evaluating of a Solar Barbecue by Using Evacuated Tubes

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***Abstract*—** In this paper, a simple, cheap and portable evacuated tube solar grill has been fabricated and evaluated in Iraqi climate. All the experiments were conducted in the site of the Ministry of Science and Technology in Baghdad, Iraq with 45° tilt angle directed to the south during clear and partially cloudy days in January (8,11,13 and 15) and April(6,12 and 16) in 2015 with and without reflectors. The highest temperature was 238°C recorded on 12 April with reflectors and no load. Three types of food were barbecued namely; fish, chicken and pastry on 16 April 2015 with 33°C ambient temperature in partially cloudy weather where the highest temperature was 135°C. Chicken grilled in about 70 minutes at 134°C while fish and pastry took about one hour.

***Keywords*—** *Solar energy, Evacuated tube, Thermal efficiency.*

I. INTRODUCTION

Solar energy is abundant, free and environmentally friendly. As a result, it is a promising alternative energy resource. There are various ways to utilize this energy. Solar cooking is one of the useful applications of solar energy. In order to make different types of food ready for eating, they have to be cooked. Therefore, cooking is a necessary process for human beings. Fossil fuel based energy resources predominate with the highest share in global energy consumption for cooking [1]. A considerable amount of total energy is consumed for cooking, in India for example, energy demand for cooking account for 36% of total primary energy consumption [2]. In rural areas where inhabitants cannot be supplied with commercial fuels, people have to walk for long distance and spend few hours in order to collect firewood. The situation will be more difficult for refugees in camps where it is not easy to find wood. In addition to the negative environmental effect of the utilization of firewood, there are some serious dangers of fire and many health problems like lung disease, eye disorder and skin burns especially for children. Moreover, depending on firewood for cooking may lead to deforestation. To overcome those difficulties more attention must be paid for clean and sustainable substitutions of energy resources where solar energy will be the perfect option in this case. An important method in which direct energy from the sun is being used is through solar cooking technology, which ranges from very simple ones to very sophisticated ones in terms of technicalities [3].

II. MECHANISM OF HEAT TRANSFER IN COOKING

Energy required for cooking is consumed during two processes; sensible heating, and physical and chemical changes of food. Most of the energy is consumed during sensible heating period [4]. Energy required for cooking depends on the method of cooking. During cooking, about 20% of energy is consumed in heating up food to the boiling temperature, while 35% is spent in water vaporization and 45 % of heat is lost in convection losses [5]. Therefore, it is very important to insulate the system in order to minimize heat losses by using thermal insulation or an evacuated tube which is one of the most efficient methods to reduce convection heat losses.

III. TYPES OF SOLAR COOKERS

Any system that makes use of solar energy to boil or pasteurize water or cook food can be referred to solar cooker [6]. Generally, there are different types of solar cooking, but they can be classified into two main groups: cookers without heat storage and cookers with heat storage [7].

A. Solar Cookers Without Heat Storage

There are two types of solar cookers without storage according to the heat transfer mechanism. Direct type cookers use solar radiation directly in cooking while indirect solar cookers use a heat transfer fluid to transfer the heat from the collector to the cooking unit [8]. Direct types are box cookers and concentrating cookers.

1. Box Type Solar Cookers: Box solar cooker is an insulated container covered with a single or multiple glass sheets. It depends upon the greenhouse effect. The glazing permits short wavelength solar radiation to pass but longer wavelength coming from the objects inside the box is not allowed to back through the glass. The speed of cooking depends upon the design and thermal efficiency of the cooker. In order to enhance the performance of the box solar cookers, mirrors may be used as solar radiation reflectors. The main advantages of box cooker are the simplicity of fabrication, it can cook multiple pots at the same time, and it can be made of any size to cook large food quantity. On the other hand, it cannot achieve temperature above 150 °C.

2. Concentrating Solar Cookers: In this type of solar cookers, solar radiation is focused at a point or a line by reflectors. A solar tracking system with one or two axis may be used with concentrating solar cookers for higher energy harvesting and higher temperature up to 300°C. Therefore, the concentrating solar cooker is suitable for the types of food that require high temperatures or high rates of cooking [9]. This kind of solar cookers have the advantages of high temperature achievement and quick food cooking. The main disadvantage of direct type cookers is that they are not used indoors so the person who cooks has to be exposed directly to the sun.

3. Indirect Solar Cookers: In this type of cookers, a heat transfer fluid is utilized to transfer heat from solar collector to the cooking pot. Commercially, there are three types of indirect cookers, flat plat solar cookers, evacuated tube solar cookers, and concentrating solar cookers. Evacuated tube solar collectors ETSCs are getting popular day by day for their uniqueness as they are able to gather energy from the sun all day long at low angles due to their tubular shape [10]. Solar cooking systems using evacuated tube collectors have several advantages. They provide high thermal power and temperatures without tracking and allow cooking in the shade in addition to the fast cooking [11]. The disadvantage of solar cookers without heat storage is that they work only during sunshine hours which mean that are not used during the night or in cloudy days.

B. Solar Cookers With Heat Storage

The problem of cooking during cloudy days or off sunshine hours may be solved by thermal energy storage. Moreover, cookers with heat storage may be used indoors so there will be no need to be under direct sunlight. Basically, solar cooker with heat storage are classified into three types, sensible heat storage, latent heat storage, and thermo-chemical heat storage cookers depending upon the heat storage mechanism [12].

1. Sensible heat storage cookers: Sensible Heat Storage (SHS) is based on raising the temperature of a solid or liquid to store heat and releasing it with the decrease of temperature when it is necessary. The amount of heat stored depends on the specific heat of the medium, the temperature change and the amount of storage material [13].

2. Latent heat storage cookers: This method is based on the utilization of phase change materials (PCM). These materials store heat when they go from solid to liquid, from liquid to gas or from solid to solid. Then they release energy when they have the reverse phase change.

3. Thermo-chemical heat storage cookers: In the Thermo-Chemical Energy Storage systems, the energy is absorbed and released while breaking or reforming molecular bonds in a completely reversible chemical reaction. In this case, the storage of heat depends on the amount of chemical material and endothermic heat of reaction.

C. Description of Solar Barbecue

Solar barbecue consists of three main components: five evacuated tubes, aluminum box holding the tubes, and reflectors.

1-Evacuate tube

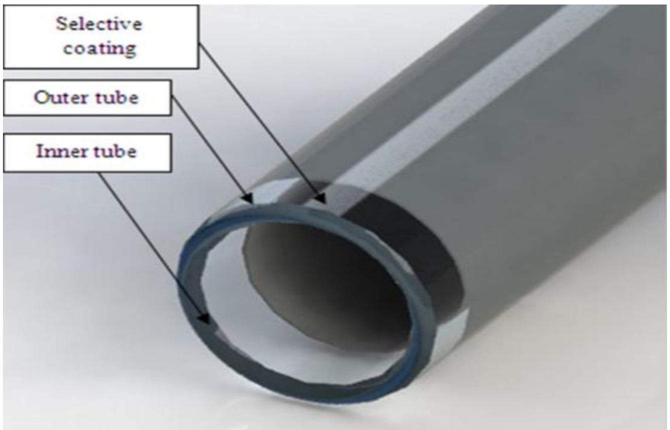

Figure 1: Evacuated tube [10].

The evacuated tube is consists of two tubes made from extremely strong borosilicate glass as shown in Figure1. The length of the tube is 50 cm and the diameter of the outer tube is 58mm, while the diameter of the inner tube is 44mm and 48 cm length, with 1.8 mm thickness each. A vacuum (P≤5×10-3 Pa) is present between the two tubes. The outer tube is transparent in order to permit light rays to pass through with minimal reflection. The transmittance of the outer tube is about 89 %. The inner tube is coated with a special selective material of aluminum nitride with zinc and copper. The absorptance of the inner tube is 93%. The vacuum between the inner and outer tubes is serving as a thermal insulation so convection and conduction heat losses are eliminated. Total aperture area of the tube is $\pi\times5.8\times50 = 911$ cm^2 with 0.73 liter.

2- Aluminum box

The tubes are fixed into an aluminum box with two rows of holders as shown in Figure2. There is a steel bar fixed under the caps of the tubes to keep them closed after putting food inside the tubes.

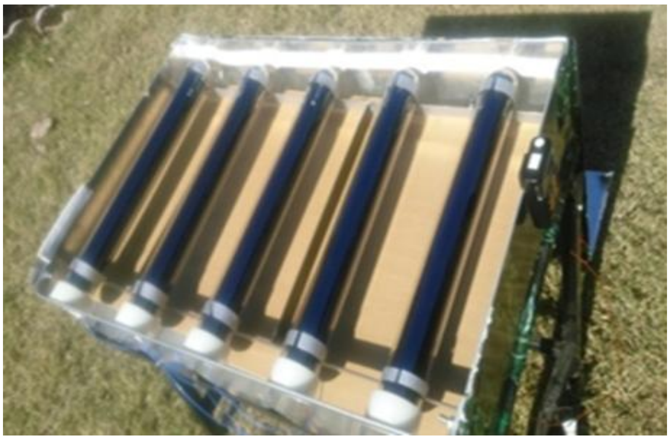

Figure2: Tubes holding box.

3-Reflectors

In order to enhance the performance of the barbecue, reflectors are used to harvest more amount of solar energy. The reflectors are made from aluminum foil and fix under each evacuated tube as shown in Figure3.

Figure3: Reflectors.

IV. GOVERNING EQUATIONS

The solar useful heat gained by each tube [14] could be determined as following

$$Qu = Ac\times\ F[I(\tau\times\alpha)-U_L(T_{mf}-T_{amb})\qquad (1)$$

where

Qu : Useful heat gaine (W)
Ac : Aperture area of tube = πDL (m^2)
F : Collector factor = 0.9 [15]
I_{av}: solar radiation intensity (W/m^2)
τ : The transmission factor of the outer transparent pipe
α : The absorption factor of the inner black-coated pipe
U_L: Overall heat loss coefficient ($W/(m^2.K)$)
T_{mf} : Fluid mean temperature = $(T_f + T_i)/2$ (°C)
T_{amb} : Ambient temperature (°C)

Collector efficiency is calculated as

$$\eta_{th} = \frac{Q_u}{A_c I}\qquad (2)$$

V. GOVERNING EQUATIONS

All the experiments were carried out in the complex of the Ministry of Science and Technology in Baghdad. In all experiments, a K-Type temperature data logger was used to record the temperature of every single pipe and the ambient temperature as shown in Figure4.

Fig.4. K-Type data logger.

In addition, a portable solar meter was used to record the solar insulation during the experiments as in Figure5.

Figure5. Portable solar meter

The solar barbecue was installed to the south with 45° tilt angle as shown in Fig.6. The thermocouples were inserted inside the tubes carefully in order not to touch the tube body.

The first experiment was conducted in partially cloudy day on 8 Jan.2015 at 16°C ambient temperature with reflectors and no load. The highest temperature was 190°C while it was 150°C in a partially cloudy day on 11 Jan. with reflectors and 13°C ambient temperature. The highest temperature was 238°C recorded on 12 April in a clear sky and 32°C ambient temperature with reflectors and no load. The grilling experiment was done on 16 April where chicken, fish, and pastry were barbecued in a partially cloudy day with 33°C ambient temperature as shown in Figure 7.

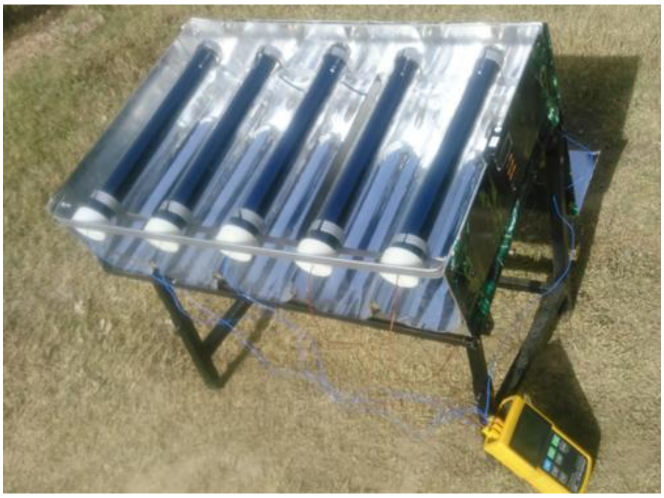

Figure 6. Barbecue installation.

Figure 7. Barbecued food.

VI. RESULTS AND DISCUSSION

After temperature in all tubes and solar insulation were recorded, diagrams in Figures (8, 9, 10, and 11) for temperature increasing with time were obtained for days (8,11, 13, and 19) of January 2015 and Figures11 and 12 for days 6 and 12 April. It is found that the weather condition is vital for temperature increasing and heat gain. The highest temperature was about 194 °C on 8 January in a partially cloudy sky, while it was 216°C in a clear sky on 19 January. Similarly, in a clear sky on 12April and it was 238°C. The highest grilling temperature was 135°C for pastry on 16 April in a partially cloudy sky. Tables1 and 2 illustrates the useful energy gained and thermal efficiency in each tube on 13 and 19 Jan. with no load. Table 3 shows the useful barbecue power and efficiency of tubes on 16 April.

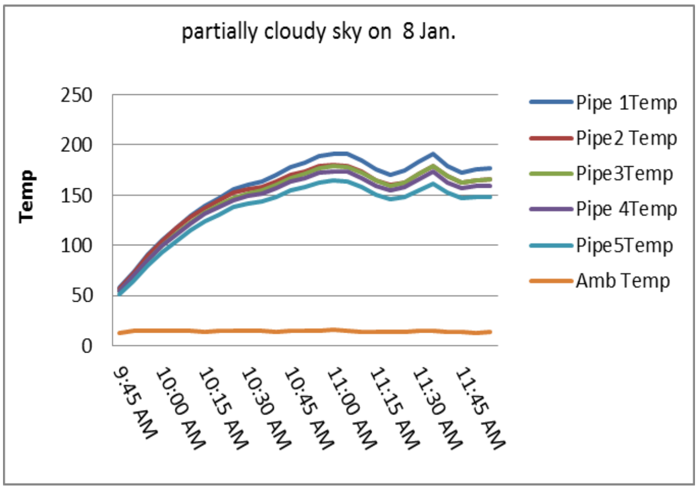

Figure 8. Air temperature inside tubes with reflectors.

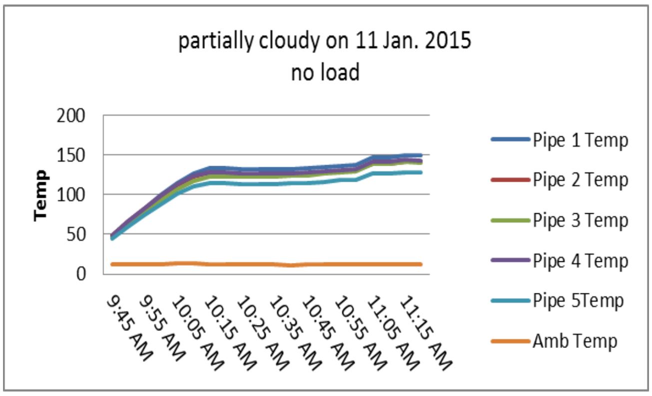

Figure 9. Temperature inside tubes with reflectors.

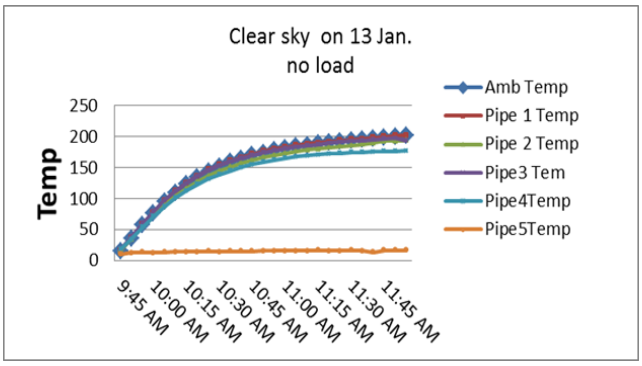

Figure 10.Clear sky without reflectors.

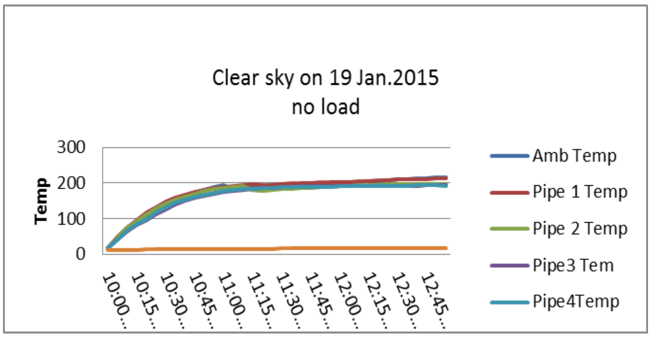

Figure 11.Clear sky with reflectors.

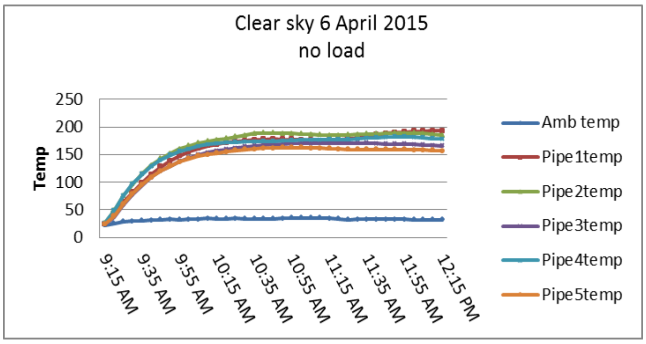

Figure 12 .Clear sky with reflectors.

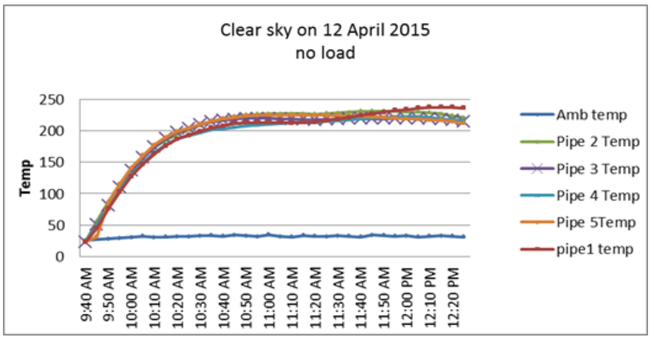

Figure 13. Clear sky with reflectors.

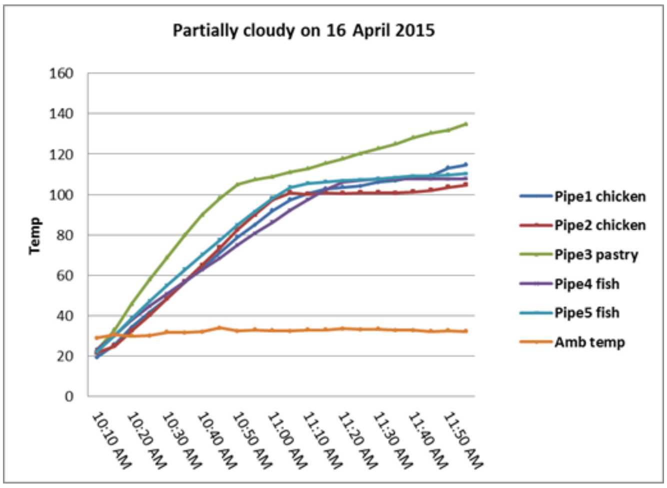

Figure 14. Barbecue in partially cloudy day.

Table1. Useful energy gained by each tube on 13 Jan.

No.	Time	T_{amb} °C	$I_{av.}$ W/m^2	Q_u W	η %
1	10.00-11.00	13	497	28.4	62
2	11.00-12.00	16	511	26	55
3	12.00-13.00	19	666	35.3	58

Table 2. Useful energy gained by each tube on 19 Jan.

No.	Time	T_{amb} °C	$I_{av.}$ W/m^2	Q_u W	η %
1	10.00-11.00	13	497	28.4	62
2	11.00-12.00	16	511	26	55
3	12.00-13.00	19	666	35.3	58

Table 3.Maximum energy gained by the solar barbecue.

No.	Time	T_{amb} °C	$I_{av.}$ W/m^2	Q_u W	η %
1	10.00-10.50	30	860	52.9	67
2	10.00-11.00	30	860	52.4	66
3	10.00-11.00	30	860	52.8	67

CONCLUSION

The main objectives of the present work are to design and fabricate a solar barbecue and to study the feasibility of solar energy for cooking and grilling applications in Iraqi climate. The results shown that the solar grill is useful in clear and partially cloudy weathers but with longer time. Moreover, the results shown that reflectors have improved the performance of the barbecue.In spite of the importance of the heat storage to be used during nights and cloudy days, the barbecue was designed without heat storage for simplicity. It is also found that variable solar energy in Iraq may be successfully utilized for variable applications.

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