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Research Article

Effect of inserting 10-PPI copper foam as a porous absorber on the solar cooker performance

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Abstract
Sustainable development is confronted with various challenges, and one of them is the scarcity of energy. To meet the needs of present and future generations, investments, technologies, and institutions need to evolve. One promising solution is the utilization of solar cookers. These cookers operate without the need for fuel or coal, resulting in cost and time savings. In the present study, two box-shaped solar cooker models were tested under identical conditions to assess their thermal performance and identify areas for improvement. The first model employed a copper absorber plate, while the second model utilized copper foam sheets with a porosity of 10 pores per inch (PPI). The experimental testing took place in Baghdad City, Iraq, in September 2022. The cookers were positioned towards the south at a latitude of 33.3° N and a longitude of 44.4° E. During the experimental testing, the copper foam with 10-PPI was used as the heat absorber plate, and various inclination angles (0°, 3°, 6°, and 9°) were examined. The results demonstrated that the solar cooker with a 10 PPI copper foam absorber achieved a stagnation temperature approximately 25.8 degrees higher than a standard absorber of the box-shaped solar cooker. Furthermore, using a 10-PPI copper-foam absorber plate reduced the cooking period in the box-shaped solar oven by up to 33% compared to a flat conventional absorber plate. The mean temperatures of the 10-PPI copper-foam absorber plate increased as the inclination angle rose, reaching its optimal internal air temperature at an inclination of 6 degrees. The equation of the cooking power provided a reliable indication that the cooker consistently cooked food and boiled water within an acceptable range.

Keywords
Box-type solar cooker, 10 PPI copper foam, Foam incline angle, Cooking power, Cooking time.

1.Introduction
The importance of reliable energy sources to a country's economic, social, and political growth cannot be overstated [1]. Sustainable development faces many challenges, including energy shortages. Investment, technology, and institutions evolve to meet the requirements of current and future generations [2]. With consumer prices that reflect the whole cost of energy to the economy, renewable and clean energy sources must be used sustainably [1]. The global energy crisis has intensified due to a deeper issue. Climate change and global warming are one of humanity's biggest issues in the 21st century, emphasizing the need for sustainable energy solutions [3]. Temperature changes aren't the only issue.

The decline in nonrenewable energy use is hurting sustainable development, which aims to preserve resources for future generations and reduce environmental impact. The economic and regulatory mechanisms needed to develop sustainable renewable energy markets adjust to changes in the cost of renewable energy and fossil fuels, their social and environmental consequences, and the costs of correcting them. Due to these and other considerations, more nations are considering renewable energy to reduce their fossil fuel dependence and defend their economy. Some recommended treatments are inapplicable due to energy use differences between countries. In desert countries like Iraq, firewood is the main cooking fuel. Environmental concerns are making firewood scarce and pricey in some areas. Hence, fuel wood use has increased demand for its replacement, causing

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deforestation, soil erosion, and other environmental issues. Solar energy's non-depletion makes it a promising renewable energy source [4].

One viable alternative is the solar cooker. This cooker doesn't need fuel or coal, saving trees and time. Solar cooking can help women in saving the time, and lessen their environmental effects [5]. They developed solar cookers to cook food for their families, minimizing firewood use and smoke exposure. The most common solar-cookers are heat-trap box-cookers, parabolic cookers, and panel cookers. Solar radiation within the enclosure (cooker) is converted into thermal energy, which causes the temperature within it to increase. The first form is heat-trap box cookers usually produces a lot of heat and can store many pots inside it. The second form of solar cooker is parabolic, which quickly heats up. This sort of cooker is harder to use than others because it needs constant monitoring and adjusting. Last form is panel solar cooker. Panel solar cookers have box and concentrator absorber advantages. Due to its affordability and user-friendly nature, this particular solar cooker has gained significant popularity. Because of the many aspects to consider, designing a highly efficient solar cooker is difficult. A solar cooker absorber plate redesign by researchers contributes to the improvement of end-user experience [6]. Inefficient energy utilized in the solar box cooker takes too long to cook food. Solar cookers lost popularity, and Iraq hasn't adopted solar cookers as much as other countries. To promote solar cookers, the absorber plate must be redesigned.

Solar cookers have major issues due to the physical qualities of air, namely air's poor thermal capacity and heat transfer coefficient. The effectiveness of a solar cooker is further degraded by the fact that it loses roughly fifty-five percent of the energy from the sun's incoming rays [7]. Due to the low heat transmission coefficient, air solar cookers are not very effective. This is accomplished by improving the heat transfer coefficient's value by coating the absorber plate's top surface in artificial roughness [8]. Previous studies have made use of highly-effective approaches for enhancing thermodynamic efficiency, such as the methods of decreasing the solar cooker's heat loss. Fins can improve heat transfer, while phase change material (PCM) can lengthen the duration between ventilation cycles. In addition, porous material placed in the flow route of a solar cooker as an absorber plate is a passive approach that gives a high rate of heat transfer.

Metal foam is a low-density porous medium that exhibits unusual mechanical and thermodynamic characteristics. At present, the most common type of heat sink is metal foam. It is lightweight, inexpensive, resistant to corrosion, and has a high heat conduction. A number of contrivances helped to the increased heat transfer associated with the use of metal-foams. These include the contact between a fluid moving through a solid-material foam and the porous-matrix, which it has a more significant impact on the rate at which heat is transferred from the hot components to the fluid. Surface area per unit volume is the second most significant aspect in heat sink performance because it controls heat-dissipation via convected heat transfer [9]. Metal foam are a type of porous material with unique properties that find use in heat transfer systems of varying architectures. Ultra-light, homogeneous pore size, and high porosity are only a few of the benefits of metal foams, which were invented in the 20th century. The ratio of heat transfer surface high area to total volume (500106 m^2/m^3), along with the great thermal-conductivity relation with the solid-matrix and the air transient over it, results in efficient heat transmission, fluid flow and heat transfer improvements in metal-foams have garnered huge interest because of their potential in the last few years. for enhanced mixing of flows and the winding routes inside the porous matrix [10]. Among the various mechanical features of metallic foams are:

1 Small in mass.
2 Having an extremely high capacity for heat transfer.
3 Third, it can withstand heat, cold, humidity, and impact without breaking down.
4 Effective energy absorption from influences.
5 The twisted flow channel provides superior mixing of the fluid.
6 The ability to dampen noise is superb.

In addition to its thermal qualities and heat transfer duties, metal-foam can be utilized as a guide to the fluid flow when arranged in a solar cooker. Metal foam may be easily cut and shaped into a variety of shapes before being placed into the solar cooker at varying heights. The benefits of fluid disruption include distorting the flow structure and dispersing heat across the entire region. The fluid fluxes inside the solar cooker can benefit from the open-cell metal foam structure's having few pores and poor permeabilities and potential as an excellent instructor and turbulator [11].

This study aims to examine the efficiency of solar cookers by using experimental testing of a prototype that combines an absorber which is conventional and a copper-foam plate with an isolated experiment solar cooker. In this paper, metal-foam absorber plates' impact on the solar cooker's efficiency will be investigated and reported. The following plan can be implemented to achieve these objectives:

- Plan, build, and measure the efficiency of a solar-cooker integrated by a conventional and a copper foam absorber plate.
- An experimental study using a fullscale models of a connected solar-cooker in Iraq conditions.
- Install a standard, flat-plate cooker with a smooth surface to use as a benchmark against which other cookers can be evaluated.
- Measure the predetermined thermal and hydraulic parameters utilizing experimentation.
- Examining how heat transport and temperature distribution are affected by changing the problem's parameters.

This paper is organized as follows. Section 2 presents the literature review. Section 3 covers the methodological investigation. Section 4 discusses the results. Section 5 elaborates on the discussion. Finally, the paper concludes in section 6.

2.Literature review

The following are some of the methods reported by different researchers in their literature for enhancing the box-type solar cooker. Nayak et al. [12] tested a box-type solar cooker with a finned cooking pot for thermal performance in Talcher, Odisha, India environment. The experiment used a box-style solar cooker with equal-sized finned and unfinned cooking pots. Fins elongate the surface, transferring heat from the oven to the cooking vessel more efficiently. Solar cookers were tested regularly. This three-month research used 1 L water loads (Sept.-July 2016). Pot type, solar intensity, and local time were also examined as cooking efficiency factors. In sunny conditions, an unfinned pot reached 93 and 102 degrees Celsius, but in overcast weather, it reached 70 and 76 degrees Celsius. In foggy conditions, a finned pot's efficiency is 53% and an unfinned pot's 50%, while in clear conditions, they are 72% and 54%, respectively. Sun radiation and cooking vessel affected the cooking temperature. Modern solar cookers are cheap and easy to make. Ukey and Katekar [13] discussed about Octagonal box solar cookers maximize solar energy capture and heat generation. Concentrated solar beams swiftly boost the temperature to cook. The modified cooker has to reflect sloped surfaces on all eight sides. Copper base plates maintain cooking heat. The new cooker has 19.767 Watts of cooking power and a first merit value of 0.3027. Cooking uses 49.639 W on average. The 38.36%-efficient octagonal solar cooker is proposed. The redesigned octagonal cooker has 23.52% higher cooking power and 26.55% more efficiency than box-type solar cookers. The adapted solar cooker meets the Bureau of Indian Standards "A grade" criteria. Noman et al. [14] discussed about the purpose of this study is to create a basic statistical model for gauging the efficacy of a solar parabolic trough cooker in different climates. It took place in a natural setting and was intended for private use. The apparatus used in the study was a 9.867:1 concentration ratio polished stainless steel parabolic trough solar oven. The research shows that the theoretical efficiency of a parabolic trough is around 50%, while the experimental efficiency is around 30%. In addition, the highest temperature of 37.2 degrees Celsius was recorded at the parabolic trough's outflow. Under stagnant circumstances, however, the parabolic trough cooker was able to heat water to a maximum of 53.6 degrees Celsius. In addition, the exergy efficiency for direct heating was found to be in the range of 7.6 102 - 2.1 102%, while the energy efficiency for cookers was found to be between 6.5 and 0.11%. The findings will be useful in developing a home cooking device. Engoor et al. [15] discussed about the box-style solar-cooker is a basic solar energy-gathering device for humid homes. This experiment tests if aluminum fins on solar cooker pots improve performance. Water is cooked in one of four cylindrical aluminum cooking containers for five days—two without fins and two with fins of 25 mm, 35 mm, or 45 mm. In all four combinations, confined water reaches 102 degrees Celsius. Outside testing lasts two to three hours at 90–100 degrees. The 45 mm finned arrangement achieves 56.03% thermal efficiency and 58.54 W/m2 °C heat transfer. The 45 mm finned pot boils water for 2 hours and 17 minutes. Due to their larger heat transmission surface, finned cooking pots perform better in stagnation and sensible heating tests. Vengadesan and Senthil [16] In tropical climates, the box-style solar cooker can be used for home cooking thanks to its ease of use and ability to harvest solar energy. In this exercise, the benefits of installing aluminum fins on solar cooker pot lids are examined. Experiments using finned and unfinned cylindrical aluminum cooking vessels with fin lengths of 25, 35, and 45 mm are performed for five days at a time in outdoor settings. Water is seen to reach a maximum temperature of 102 degrees Celsius in each of the four possible arrangements. Outdoor testing lasts for about two to three hours, during which time the temperature is held between 90 and 100 degrees Celsius. With a 45 mm fin thickness, we can achieve a thermal efficiency of 56.03 percent and a heat transmission coefficient of 58.54 W/m2°C. It takes the cooking pot with 45 mm fins 2 hours and 17 minutes to bring water to a boil. Stagnation and sensible heating experiments reveal that thanks to their larger fin area, finned cooking vessels outperform their unfinned counterparts in terms of thermal efficiency. Singh [17] was involved in the improvement of a solar-cooking device that allows for interior, controlled cooker. This innovative tool introduces a novel concept in solar radiation transmission for indoor cooker using a parabolic collector to transfer heat to a heater plate placed in the kitchen. A light-dependent-resistor (LDR) centered microelectronic solar-tracker is built into the parabolics collection to keep it pointed directly at the sun at all times. Using a charge controller, PV screen steadily replenishes a 12-V batteries. To keep the heat transfer fluid circulating through the heater plate's coil, a direct current (DC) motor-pump combination gets its power from the battery as well. To ensure proper cooking and to preserve food's nutritional content, the pump is thermostatically controlled to keep the heater plate at the ideal cooking temperature. In the line of heat transfer fluid are a digital-thermometers, pressure-gauges, and a aid by-passes valves are just some of the safety and efficiency features built into the system. The device's effectiveness and capacity to reduce carbon dioxide emissions are assessed through exergy and enviroeconomic analyses. Tawfik et al. [18] discussed about integration of thermal energy storage (TES) is crucial for maximizing solar power systems' output. If you want to finish your solar cooking activity even when the sun isn't shining as brightly, adding thermal storage to your setup is a must. This study details the thermal performance of a solar cooker using a tracking type bottom parabolic reflector (TBPR) and an absorber plate with built-in thermal storage. As a phase shift material, paraffin wax is used by scientists as a heat storage medium. Two versions of the TES integrated-cookers are verified in order to determine how adding or removing the TBPR solar cooker might affect the thermal performance parameter (TPP) in the field: SC1 and SC2. The first performance figure (F1) and the cookers optics thermals ratio (COR) are two examples of TPPs. A financial assessment of the stove is possible by calculating the levelized cost of cooking a meal (LCCM). SC1 and SC2 commonly have COR values of 0.118 and 0.140 (m^2K/W), respectively. In 75-82 minutes and 61-66 minutes, respectively, the SC1 and SC2 cookers reach the standard cooking temperature, and both maintain a heat of 70-72 degrees Celsius until 18:00 h in the evening. Both the SC1 and SC2 stoves have an LCCM of around 0.024 0.0005 USD/Ml, which is very close to one another. The additional advantages of SC2 include extended cooking times and an increased annual number of cooked meals. (prepare meals in the early morning and late afternoon). As a result, the current work elucidates the connection between the Cost-benefit analysis of the suggested solar-cooker with heat storage and TPP rating. Saxena et al. [19] discussed about heating and power generation are two of the primary applications of solar energy, which is also a major energy source with exceptional sustainability. There is a wide variety of energy storage materials that can be used to improve the efficiency of solar heating devices. Using a hot box cooker, the authors of this study tested the thermal storage capacity of three blackened pebbles, small chunks of masonry bricks, and little aluminum balls are all different types of sensible heat storage materials. All of these items have been set atop the stovetops used in the tests. There have been a grand total of three attempts at creating a stagnation and sensible heat test setup. The authors have honed down on a straightforward and low-cost strategy for increasing the box cooker's thermal efficiency through the use of sensible heat storage materials, which is particularly useful for those living in rural or far-flung areas. Do-it-yourself instructions make it possible for even the least technically savvy shopper to implement the recommended approach in a box cooker. Consumers benefited from the cooking experiments, proving the viability of inexpensive energy storage materials. These findings further suggest that it is possible to implement any of the tried models, most notably the best-configured cooker, which used aluminum balls as its heating elements. This stovetop has an approximate thermal efficiency of 59.61%, a cooking power of approximately 75.21 W, and a thermal storage capability of approximately 09 h/day. The best-configured cooker is predicted to cost around $47.06, with a return time of around 3.11 years. Sagade et al. [20] meted sustainable development goals with use the solar cooker. Solar concentrating cookers (SCCs) are often used for cooking at medium to high temperatures. The collector's reflecting surface of a given SCC design reflects and concentrates solar flux, which in turn heats the cooking pot/receiver. As a result, measuring the concentration-effect is crucial, as is determining the effectiveness and role of the reflecting surface in the overall study and grading of the SCCs' opto-thermal performance. In this paper, offered a thermal approach for calculating the effective concentration ratio (C) of any given SCC configuration. The SCC was subjected to two sets of thermal tests, one with and one without a reflecting surface. The investigation of the SCC's thermal and optical performance is complemented by remarks on the importance of determining C, since it enables the quantification of a realistic concentration ratio. For the SCC employed here, we obtain a mean value of 4.998 for C and a geometric concentration ratio of 12.35. This finding proves that the concentrating surface works as intended. Therefore, C is a useful method for grading SCCs since it can be used to measure the efficacy/degradation of reflecting surface performance across various SCC designs. This technique has the potential to benefit different solar concentrating collectors with a variety of layouts. Ruivo et al. [21] estimated solar cooker performance characteristics by assuming a linear relationship between the cooker power and the temperature delta between the load and the surrounding air. For some solar cooker designs, this method may not work well. In this study, we examine and contrast the linear regression with a non-linear regression obtained by fitting the observed load temperature to a polynomial of the second order of exponentials. A panel cooker and a box cooker's experimental curves were used to evaluate the two regressions. Over a sizable portion of the test period, the panel cooker's experimental plot confirmed the expected linear trend. Only the initial and final measurements were somewhat off from the experimental results. However, non-linear regression yielded much closer agreement between the experimental points and the regression plot compared to the box solar cooker. With this in mind, In light of the need to revise the existing procedures for analysis and reportage the efficent of solar cookers, the proposed method might be seen as a feasible solution that should be explored. Aquilanti et al. [22] erected and tested four different solar panel cookers simultaneously in the field to evaluate their thermal and optical capabilities in a controlled environment. Because of their low manufacturing costs and do-it-yourself ease of assembly, the Kimono-funnel, duals set plate cooker, and cookit were all considered. One of the authors is responsible for the groundbreaking Kimono cooker, which has never before been the subject of academic investigation. Three separate seasons were spent testing the four different stoves outside in Ancona, Italy. With the same quantity of water (1kg) in a normal cake pan within a glass bowl acting as a heat trap and under no load conditions, the cookers were tested in two different configurations, one with a larger aperture area and the other with a lower aperture area. Although both setups excelled, one was superior to the other depending on the sun's elevation: low to medium versus medium to high. It was found that the Kimono and Funnel cookers perform best at low to medium and medium to high solar elevations, respectively. When comparing the two cookers, the latter took slightly less time to bring water to a boil (1.66 hours on average over all three sets of tests) than the former (1.74 hours). At low to medium sun altitudes, the Cookit performed well whereas the dual setting panel cooker was unable to bring water to a boil. In Aquilanti et al. [23] study, a new type of solar cooker was created by modeling the inside cooking chamber after a Newton prism. The device is distinguished for its simplicity in design, operation, and portability. It is constructed from ordinary, low-cost components. The proposed cooker utilizes wheels at its dishonorable and a guide method to adjust the angle of the reflection surface, allowing it to follow the sun as it moves across the sky while in operation. The effects of the wind and its thermal and optical properties were measured through experiments. In this case, ideal angles for monitoring the reflecting surfaces were determined by simultaneously testing two identical prototypes, one of which was protected from the wind. Water and glycerin were used in a series of load-free and load-bearing experiments. Even at somewhat high temperatures, the results demonstrated the solar cookers' superior thermal performance. Stagnation was at around 137 degrees Celsius for both prototypes. The insulated cooker typically heated 2 kilograms of water to 90 degrees Celsius in about two hours and 2 kilograms of glycerin to 110 degrees Celsius in less than three hours. The unprotected prototype took slightly longer in these tests. Patel [24] using a solar cooker to prepare meals is a terrific way to conserve the plentiful solar energy that is available and cut back on harmful emissions. In the current work, a trapezoid-shaped solar cooker with a circular and triangular embossed inner surface was created so that the most possible incident solar energy could be captured, converted into thermal energy, and then used for cooking. This was accomplished through the formation of a radiation network. The primary goal of this presentation is to compare the thermal efficiency of a round solar cooker, a triangular solar cooker, and a solar cooker that uses sand as a heat storage medium. Zhou et al. [25] proposed the state-of-the-art solar cooking system (SCS) with thermocline rock storage. During charging, heat is transferred from the accumulators to the rock via thermal oils, and then that heat is released in the cooktop unit. A credible hypothesis is first used to estimate a home's energy use. The effectiveness of the cooktop unit's heat transmission and the SCS's yearly running performance is then analyzed using mathematical and simulation models, respectively. Thermocline storage in a rock bed is compared to thermocline storage in a single tank and thermocline storage in two tanks. The annual operating performance of SCS is improved and the initial investment cost is reduced, according to the simulation results, when a rock-bed thermocline storage unit is used. The economic analysis reveals that the SCS has a levelized cost of cooking energy (LCOC) of 0.3884 USD/kWh, an LCCM of 0.953 USD/Meal, and a solar fraction (SF) of 71%. When compared to using an electric or natural gas stove, the SCS reduces annual carbon dioxide emissions by 1.75 and 0.52 tons, respectively. Goyal [26] Improving solar cooking's commercial viability and dependability requires work on energy conversion techniques and thermal storage. Researchers have discovered a wide variety of heat storage materials, but none of them are perfect. All three types of heat storage media-latent, sensible, and thermochemical—are covered in this overview, along with the necessary properties for effective storage and retrieval. Researchers' focus has turned from thermochemical heat storage to solar cooking because thermochemical materials have unrivaled features for storing heat at ambient temperature without losses. The latest method for improving heat transfer, difficulties associated with using a flexible storage container, the ideal placement of foam, the segregation characteristics of nanoparticles, and the breakdown of membranes in encapsulated materials are all covered in detail to better equip researchers with the information they need. Getnet et al. [27] present the design, construction, and experimental testing of a flat plate collector-based indirect solar cooker that uses a PCM. An academic research examined the performance of solar cookers with and without reflectors. The thermal storage unit uses stearic acid as the PCM, and four plane reflectors are arranged on each side of the collector to maximize the sun's rays. With four reflectors, the average daily increase in reflected solar radiation was 42.3%. The results showed that without reflectors, FPC can get the average temperature of the absorber plates up to 130 degrees Celsius, the water temperature out to 103 degrees Celsius, a maximum energy efficiency of 79%, and a maximum exergy efficiency of 48%. The indirect solar cooker had a system efficiency of 19.04%. It was determined that the cooker had a utilization efficiency of 22.3% and a characteristic boiling time of 15.7 min/kg. Koshti et al. [28] using solar energy (a sustainable resource) to prepare food has shown to be an appealing method. For the weather in Prayagraj, Uttar Pradesh, India, two modified solar cookers (MSC) were developed and tested: the "Modified solar cooker with an inclined cover" (MSCIC) and the MSC. In this study, we compare and contrast the thermal efficiency of two transparent solar cookers of varied geometries and aperture sizes. Both types of cookers' pots have had the same amount of water added for the testing. MSC have been compared in terms of their impact on a number of thermal metrics like pot water temperature, figure of merit, thermal efficiency, and energy and exergy. Similar results for immediate exergy and energy efficiency have been observed for both MSCIC (6.1%) and MSC (7.2%). This suggests that the two cookers had similar heating performances. The MSCIC and MSC experimental results were found to be in a reasonable degree of agreement.

It is clear from a survey of the existing literature that researchers have not yet looked at how different absorber plate geometries affect the efficiency of box-type solar cookers. To that end, this paper's primary deliverable is a set of experimental results from the first run of a solar cooker with a box shape and a porous absorber plate. The porous absorber increases the speed at which heat is transferred to the cooker's air [29]. Many researchers have tried to improve the efficiency of solar air heaters and other sun thermal conversion equipment by employing this technical method.

This paper's primary contribution is an experimental dataset that was acquired from a porous absorber solar cooker. The porous absorber is constructed out of Cooper foam metal foam with 10 pores per inch (PPI). The absorber aids the rapid heat transfer from the air within the cooker due to its porous nature.

3.Methods

3.1Description of the solar cookers

The absorber plates of the two box-type solar-cookers that have been created for use in the wild are different shapes, but otherwise, they are identical. The solar cooker in the form of a box that was utilized for the experiments is shown in *Figure 1*. Solar cookers in the shape of boxes were constructed with the assistance of local professionals using materials that were easily accessible. The experimental solar-cookers are comprised of two solar box-cookers that are identical to one another. The date palm bark that lines the interior of the wooden box serves as insulation for the case's contents. The top of the cooker is made of glass and features a hinge that allows it to be opened to an angle of 45 degrees. It is fastened to the casing on one side. The glass cover enables more of the sun's rays to penetrate the cookers while also preventing heat loss that would otherwise result from the cookers' being exposed to the surrounding environment. The door that opens at an angle of 45 degrees is constructed up of two panels of glass that can be spaced apart by a total of 2 centimeters. The thickness of each individual glass panel is 6 millimeters.

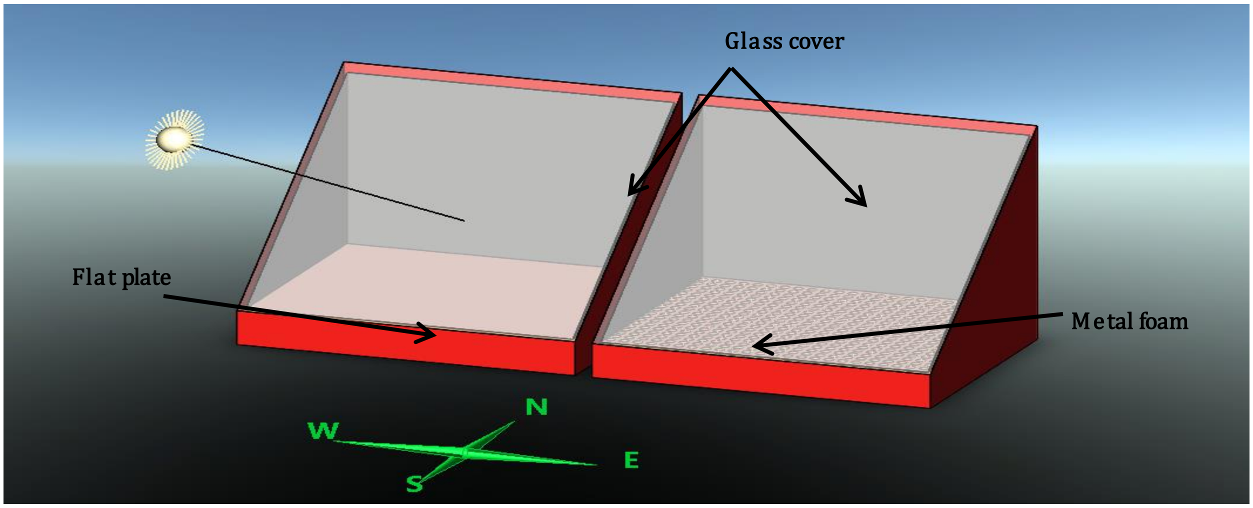

Figure 1 Schematic drawing of the box type solar-cookers

The first box solar cooker used an absorber plate that has been fabricated from copper and the absorber copper plate is fixed to the bottom side of the solar cooker. The dimensions of the absorber plate sheet were 50 cm in length, 60 cm in width, and 1 mm thick. The second box solar cooker used 10 PPI of copper foam sheets and has a dimension of (50×60) cm2 and a depth of 10mm. In the copper-foam plates, the finished shape of their implementation was displayed in *Figure 2*.

Figure 2 Photograph of the copper foam sheets (10 PPI)

In the experimental testing, copper metal-foam 10-PPI is used as an absorber media at various incline angles (0°, 3°, 6°, and 9°), and the results of these tests are compared to those of a standard flat absorber plate to determine which provides superior performance. As indicated in the image in *Figure 3*, the absorber angle of the copper foam sheet can be set by suspending it from one side and lifting it from the opposite side using a screw that is fixed to the wooden frame of the solar cooker.

3.2 Experimental study

The performance effect of two prototypes of box-type solar-cookers was compared in an experimental study conducted under identical conditions. To accomplish this, many experiments were carried out in September 2022 at 33.3° N and 44.4° E (latitude and longitude) in Baghdad City, Iraq, with south-facing sun cookers. To collect the most possible solar energy during each trial, two identical solar-cookers were set up close to one another on a common stand and manually rotated 15 degrees in either direction every 15 minutes. In the study, two box types solar-cookers were used which were shown close to one another on the experimental platform in *Figure 4*.

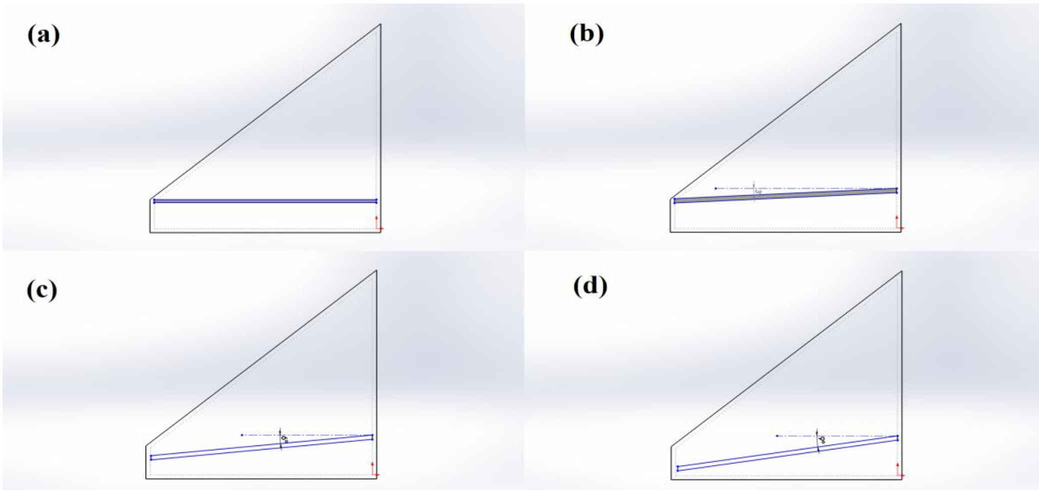

Figure 3 Schematic diagram for solar cooker with a different angle (a-0°, b-3°, c-6°, and d-9°)

Figure 4 Photographic picture for experimental apparatus

Below are some of the procedures and tests that are conducted:

- Stagnation tests: Together solar-cookers placed in direct sun rays at the same time, but without food.
- Water heating test: each cooker had a cooker pot containing an equal quantity of water heated to the identical temperature placed on its absorber plate.
- Change the angle of the metal foam layer inside the cooker to various inclination angles (0°, 3°, 6°, and 9°).
- Cooking power: The heat-capacity and mass of the water included within the cooking pot will be produced by the change in water temperature for every ten minutes. This product will be divided by the 600 seconds included during ten minutes, as the following Equation 1 [30]:

$$P = \frac{T_2 - T_1}{600} \times m \times C_p \qquad (1)$$

- Standardizing cooking power: Through the use of the below Equation 2, the value of cooking power (P) is multiplied by the standard and normalized solar irradiance, which is (700 W/m^2), and then that result is divided by the average worldwide irradiance for that interval [31]:

$$P_s = p \left(\frac{700}{I}\right) \qquad (2)$$

- Temperature difference: It is necessary to deduct the average ambient temperature ($T_{a)av}$) for each interval from the average water temperature ($T_{w)av}$) for each corresponding interval, as the following Equation 3:

$$T_d = T_{w)av} - T_{a)av} \qquad (3)$$

Absorber plate temperature, hot air temperature as measured in the middle of the cooker's interior volume, ambient-temperature, and horizontal-irradiance were all logged at 1-minute interval for each cooker by a data-logger systems. A (TES-1333) type pyranometers was utilized for measures solar radiations (0-1400 W/m^2, 2 W/m^2 accuracy). Copper-constantan thermocouples were used to take all readings (range: 0 to 300 degrees Celsius; accuracy: 0.5 degrees Celsius). Each cooking vessel has a small hole drilled into the middle of the lid so that the same type of thermocouple can be used to measure the water's temperature during water heating tests.

To get an accurate reading of the temperature distribution in the air solar cooker, thermocouples were utilized and put in various positions [32]. To prevent the thermocouples' movement from skewing the readings they provided, epoxy was used to secure them in place. The thermocouple that was used to measure the absorber plate and the glass cover had a layer of aluminum foil placed on the tip of it so that it would be protected from the effects of heat flux and airflow. As shown in schematic *Figure 5*, the inserted type thermocouples were mounted at the cooker plate at 11 different positions for each solar cooker to determine the average temperature of the plate. In addition, two thermocouples had been inserted inside each cooker, one to measure the air cooker temperature and another to measure the water temperature in the pot in each cooker. Also, one thermocouple is fixed on the glass surface in each cooker so that the temperature of the glass surface could be determined. In last, one thermocouple in the environment for measured ambient temperature.

3.3 Error analysis

The measurement system was made up of a series of components, each of which had its own level of precision. The technique suggested was utilized to evaluate the uncertainty of experimental quantities. *Table 1* contains the specifics of the uncertainty calculation. There are two aspects that influence how well experiments work out. Measurement precision and attention to detail in the testing apparatus.

The discrepancies in precision are due to;

1. The consistency of the wall's heat distribution.
2. The proper placement of the thermocouple's anchor.
3. Inaccuracies in measurement tools.

It's undeniable that mistakes in measurements accounted for the bulk of computation mistakes.

As a result, *Table 1* provides the following information regarding experimental mistakes that may occur in the variables used:

Table 1 Measurement instrument imprecision

Substantive Factors (v)	Intervals of Doubt (w)
Temperatures	± 0.1 ℃
Instance radiations	± 10 W/m^2
Data logger	±0.01 ℃

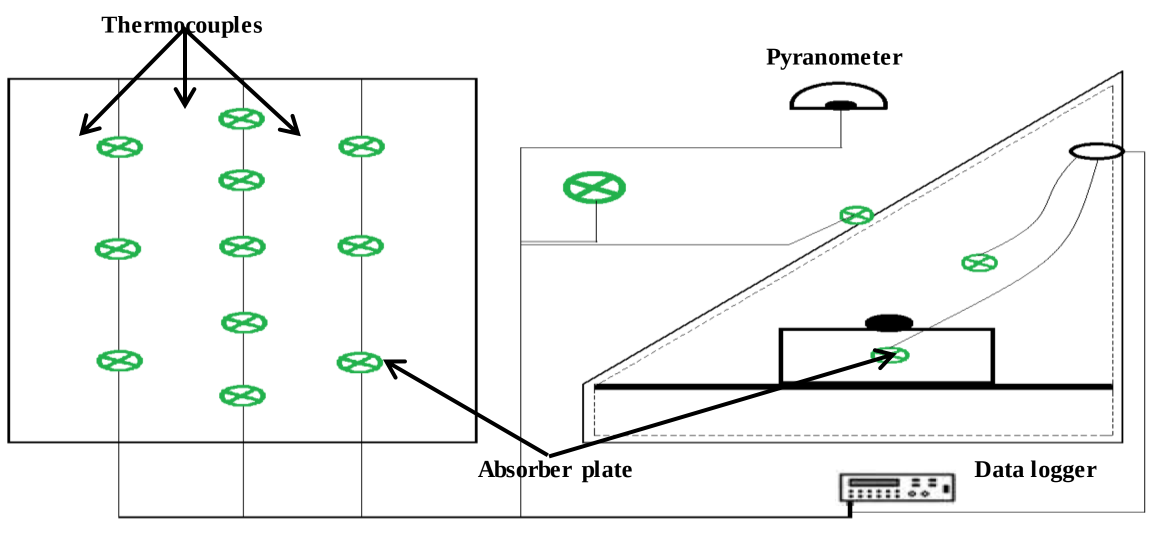

Figure 5 Schematic diagrams for the location of thermocouples in solar cooker

4.Results

4.1Stagnation tests

Stagnation temperatures of the interior hot-air in the solar-cooker with copper foam absorber plate were consistently greater than those in the cooker with the standard flat absorber plate during the tests. As it can be seen in *Figure 6* regarding the test conducted on September 8, 2022, when the initial-temperatures of the hot-air inside the two solar-cookers are the same, the two temperatures are very close to one another at the start of the test. When the temperature of the two absorber plates begins to matter, the gap between the curves widens. This is mainly because of the copper foam absorber plate's significantly larger inertia. The small PPI in copper foam lead to a rise in the absorber plate's surface-area, and consequently, an increase in the plate's permeability to the passage of air through the copper foam and to the exchange of heat between the foam and the air that is flowing through it. A total of 126.2 degrees Celsius was reached in the cooker with a copper foam absorber plate and 99.6 degrees Celsius was reached in the cooker with the standard flat absorber plate at the mid-noon of the test (12:20). As shown in *Figure 7*, the absorber plate temperature and time history for two types of solar cookers under identical test conditions on September 8, 2022 are shown. Because of the multiple reflections caused inside the holes of copper foam, the absorber plate is heated up through radiative absorption. By increasing the air surface area of the convective heat transfer plates, the near air can gain heat from copper foam, therefore the interior hot air temperature can be raised and decreased the absorber plate temperature of copper-foam. So, it is clear that from *Figure 7* the absorber plate temperature of copper-foam is less than the temperature of a standard flat absorber plate.

Solar energy usage recorder meter (TES-1333) readings were taken at Baghdad's coordinates of 33.30° N and 44.40° E to determine the solar radiation intensity in those locations. The measured intensity of solar radiation (September 8, 2022) varies with a period on pure times from 9:00 AM to 04:00 PM during the examination days in September as shown in *Figure 6*. As the day progresses, the solar radiation intensity becomes stronger until they reach their highest point about midday and then gradually weaken again as evening approaches. On September 8, at noon, the solar radiation intensity was 986 Watts per square meter at their strongest.

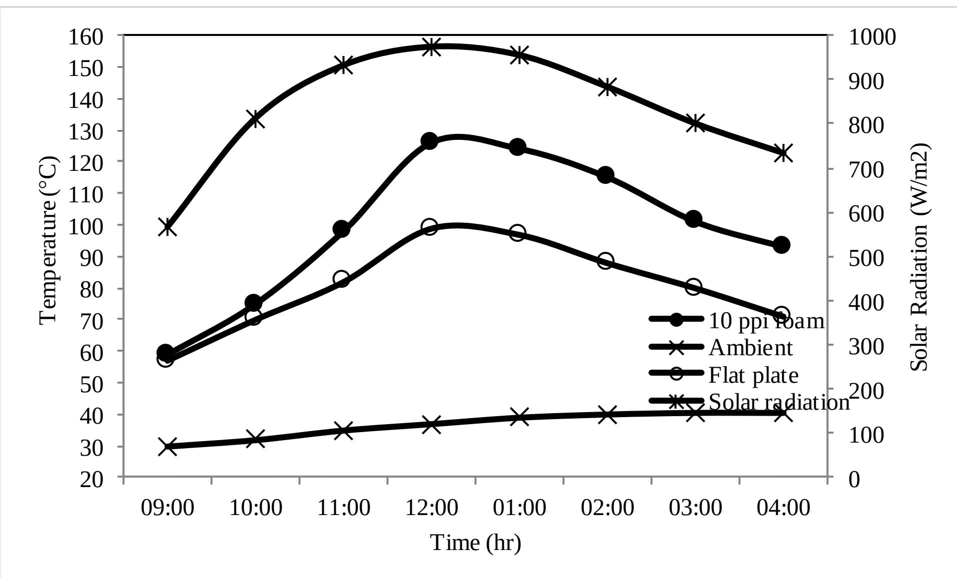

Figure 6 Comparison between internal air temperatures of two type solar cooker (Stagnation test)

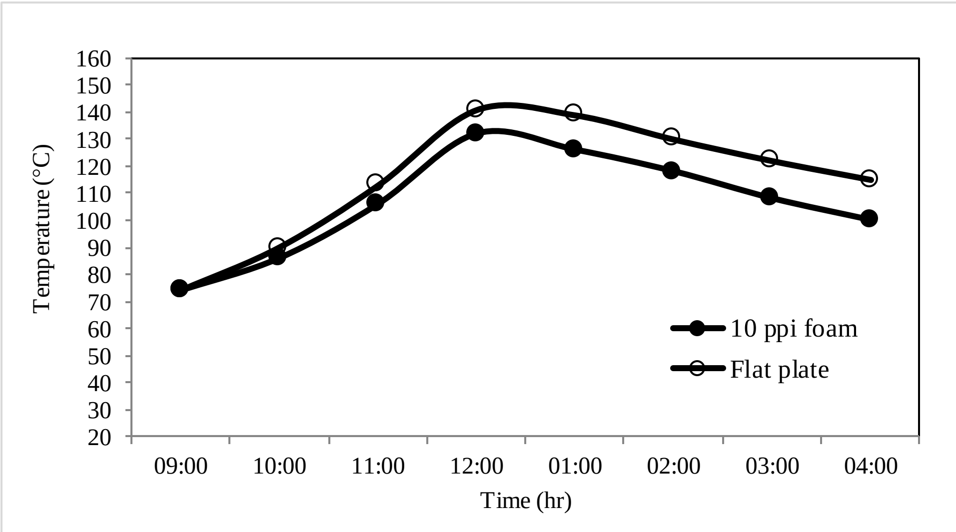

Figure 7 Comparison between absorber plate temperatures of two type solar cooker (Stagnation test)

4.2Water heating tests

All of the tests were conducted using pots that were introduced into both cookers that were identical and contained 1 L of water at the same temperature. There is a marked improvement in how rapidly water reaches boiling point (99.5 °C) when using a cooker with a copper foam absorber plate as opposed to a flat absorber plate. During the same experiment on September 11, 2022, water in both solar cookers was subjected to the same temperature and time conditions, as shown in *Figure 8*. To reach a boil, the cooker with the copper foam absorber plate took 2 hours and 24 minutes, while the other standard, cooker in same interval reached (83.2 °C). The cooker with the copper foam absorber plate took 1 hour and 48 minutes which needed 36 fewer minutes to heat up water than the cooker with the standard flat absorber a time savings that corresponds to a difference of about 33%.

The time-temperature profile of the absorber plate for two different solar cookers was recorded under controlled laboratory settings on September 11, 2022, and is depicted in *Figure 9*. The absorber plate is warmed by radiation absorption because of many reflections within the perforations of the copper foam. The absorber plate temperature of the copper foam can be lowered while the interior hot-air temperature is increased by increasing the surface-area of air exposed which convective heat transfer plates. As can be seen in *Figure 9*, the copper foam absorber plate maintains a lower temperature than the conventional flat absorber plate.

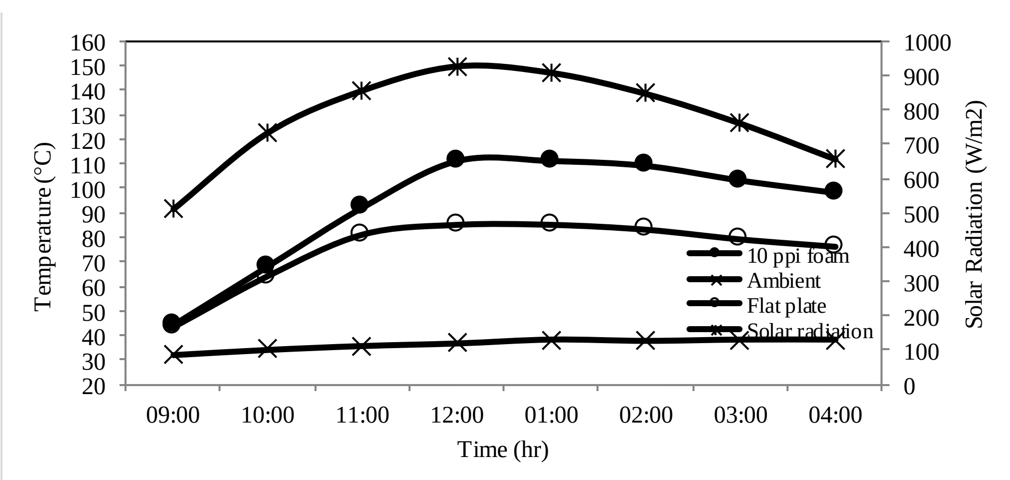

Figure 8 Comparison between internal air temperatures of two type solar cooker (Water heating test)

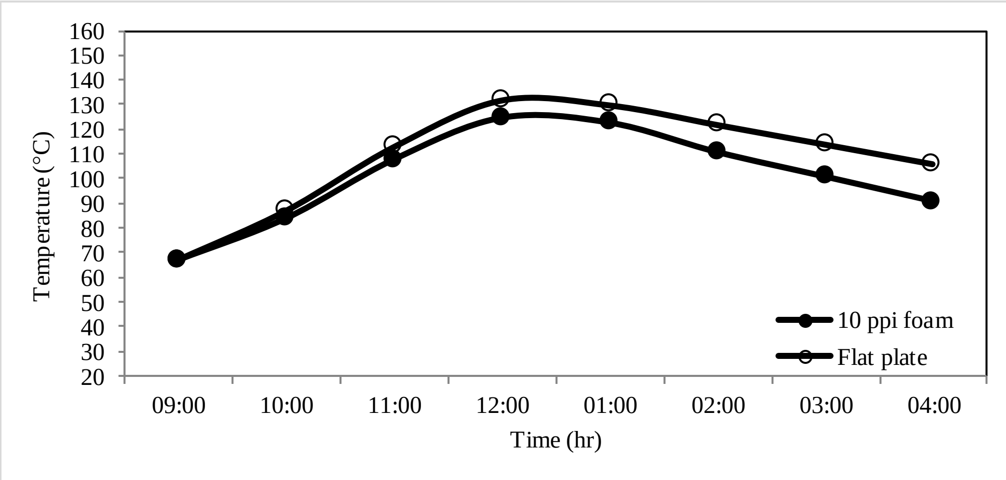

Figure 9 Comparison between absorber plate temperatures of two type solar cooker (Water heating test)

4.3Foam incline angle

Figure 10 shows variation in the mean temperature absorber plate of a copper-foam with time on September 14-17, 2022, for different inclination angles (0°, 3°, 6° and 9°). The maximum mean absorber plate temperature for copper-foam was (132.8°C) at 6° foam incline angle. It has seen the mean absorber-plate temperature of the copper-foam rises as the angle of inclination rises. This is because the boundary layer thickens with an increasing angle of tilt, and thus less heat loss from the absorber plate leads to increases in its temperature.

Figure 11 shows the internal air temperature variation for solar cooker with copper foam absorber plate with the time in September 14-17, 2022, for different inclination angles (0°, 3°, 6° and 9°). The maximum average temperature of the internal air was (126.2°C) at 6° foam incline angle. There is also the fact that the optimal internal air temperature is reached at an inclination of 6 degrees. The internal air temperature increases with the absorber plate temperature.

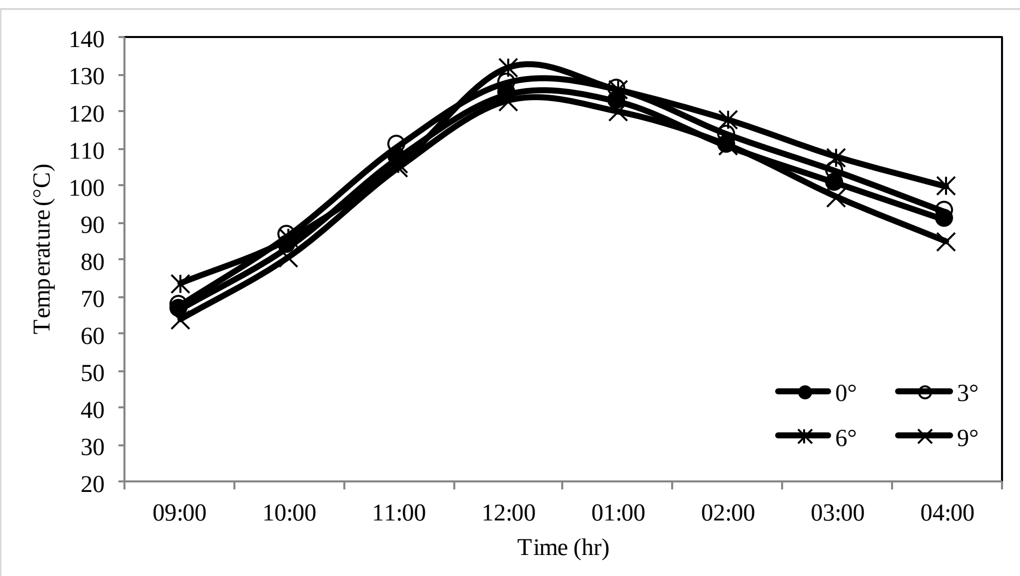

Figure 10 Comparison between absorber plate temperatures for different foam inclination angles

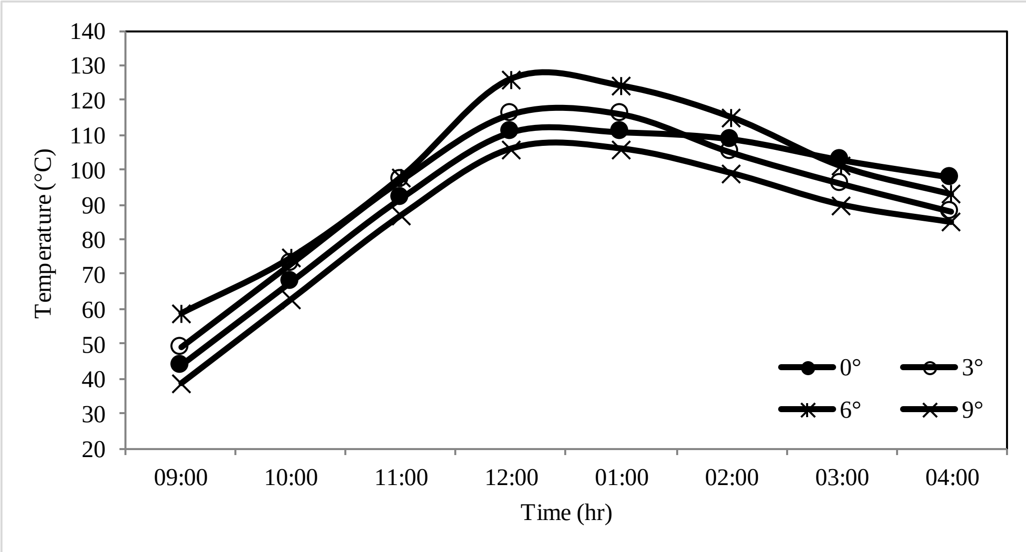

Figure 11 Comparison between internal air temperatures for different foam inclination angles

4.4The standardized cooking power

Figure 12 shows a relation of the accumulated cooking-powers (Y-axis) and the temperature-differences (X-axis). It shows that the acceptable range for the equation of the cooking-powers at each temperature-differences is (Ps= 42.142 T_d + 149.93). These results show that the solar-cooker can be relied upon for consistently cooking-food and boiling-water.

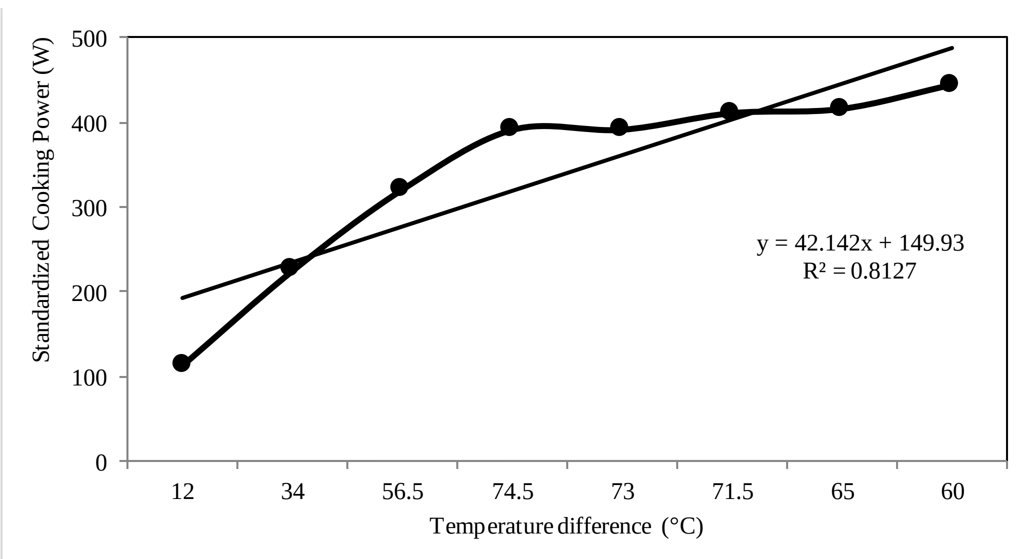

Figure 12 Relation between temperature difference and standard cooking power

5.Discussion

In this study, two box-type solar cooker models were tested under identical conditions to examine their thermal performance. The first solar cooker used an absorber plate that has been fabricated from copper and the second box solar cooker used 10 PPI of copper foam sheets. In the stagnation testing, when the starting temperatures of the hot air contained within the two solar cookers are the same, as shown in *Figure 6*, the temperatures of the two solar cookers are very close to one another at the beginning of the test. The disparity in temperature between the two absorber plates is responsible for the widening of the distance between the two curves. This is primarily as a result of the substantially increased inertia possessed by the copper foam absorber plate. Copper foam has very small PPI, which increases the absorber plate's surface area. As a result, the absorber plate becomes more permeable to the movement of air through the copper foam and to the transfer of heat between the foam and the air that is moving through it.

In *Figure 7*, the absorber plate is heated up as a result of radiative absorption. This is because of the multiple reflections that are produced inside the holes of the copper foam. By increasing the air surface area of the convective heat transfer plates, the near air can acquire heat from the copper foam. As a result, the temperature of the interior hot air can be raised while simultaneously lowering the temperatures of the absorber plates that contains the copper-foam.

In the water heating testing, when compared to the other standard cooker, the one with the copper foam absorber plate took two hours and twenty-four minutes longer to bring the water to a simmer than the other standard cooker did in the same amount of time (83.2 °C) in *Figure 8*. The cooker with copper foam absorber plate took 1 hour and 48 minutes, which required 36 fewer minutes to heat up water compared to the cooker with the conventional flat absorber; this time savings corresponds to a difference of approximately 33%. Cooker took 1 hour and 48 minutes to heat up water.

In *Figure 9* because there are many reflections within the perforations of the copper foam, the absorber plate gets warmed up as a result of radiation being absorbed by it. By increasing the surface area of air that is subjected to convective heat transfer plates, The absorber plates of the copper foam may be kept at a lower temperature while the hot air inside the insulation is raised. The copper-foam absorber plate has a much lower operating temperature than the standard flat absorber plate. In the incline angle testing, it has been observed, as shown in *Figure 10*, that the average temperature of the copper-foam absorber plate increases with the angle of inclination for each of the four different inclination angles (0 degrees, 3 degrees, 6 degrees, and 9 degrees). This is because as the angle of inclination increases, the boundary layer thickens, resulting in less heat loss from the absorber plate, which in turn causes the temperatures of the plate to increase.

In addition, there is the reality that the optimal temperature for the interior air can be achieved at an inclination of six degrees, as shown in *Figure 11*. The interior air temperature rises in part because of the absorber layer's elevated temperature.

At last, *Figure 12* gives the acceptable range for the equation of the cooking-powers at each temperature-difference and these results show that the solar-cooker can be relied upon for consistently cooking-food and boiling-water. A complete list of abbreviations is shown in *Appendix I*.

5.1Validating results

The results of the current investigates is only be validated to those of previous research on the system's performance in terms of the overall behavior of a few parameters. The current research confirms that the prior work's experimental finding [21] is usually consistent with the behavior of the air temperatures within solar cookers. As was previously mentioned, the solar cooker's internal air temperature reaches its maximum possibles value at 12:00 PM., and as can be seen in *Figure 13* and *Table 2* the heat flow increases with time. *Figure 13* and *Table 2* illustrate the variation of surface temperature distribution of the solar cookers absorber plate with time. The observed behaviors of the absorber plate's surface temperatures aligns with the experimental result obtained in the present and previous work [21]. The figure and table illustrate a clear trend wherein the surface temperature of the flat absorber plate gradually rises over time until it reaches its peak after 12:00 PM. This observation aligns with the findings discussed in the previous work [21], which indicate a delayed declination occurring after 01:00 PM.

The comparison gave an acceptable result in the trend behaviour, and this is evidence of the correctness of the results obtained.

5.2Limitations of study

The main limitation of this study is that box solar cooker used 10 PPI of copper foam sheets at various inclination angles (0°, 3°, 6°, and 9°). There are many tests procedure, one of which is the stagnation tests: Together solar-cookers placed in direct sunrays at the same time, but without food. Water heating test: each cooker had a cooker pot containing the equal quantity of water heated to the identical temperature placed on its absorber plate. Cooking power: The heat-capacity and mass of the water included within the cooking pot will be product by the change in water temperature for every ten minutes period.

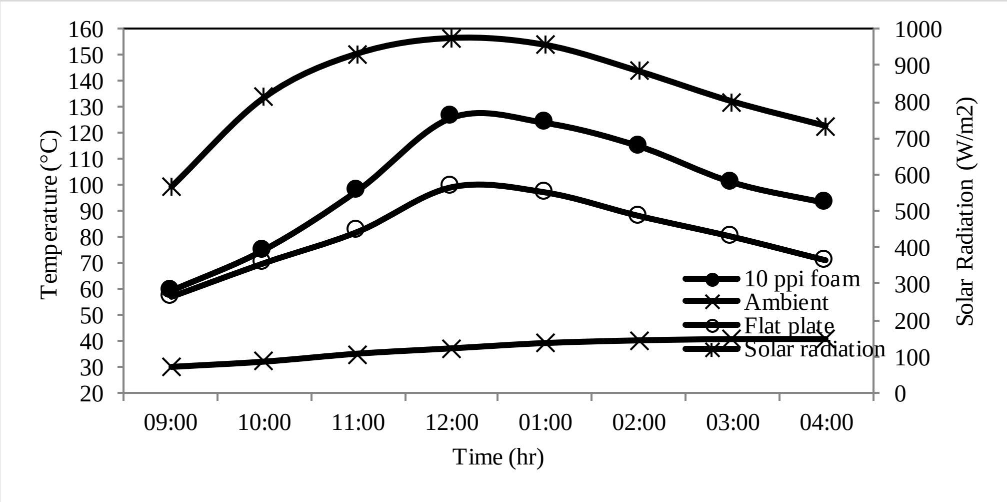

Figure 13 Comparison between internal air temperature of two types of solar-cookers (present study)

Table 2 Comparison between internal air temperature of three types of solar-cookers

Time	Flat plate (previous work [21])	Flat plate (Present study)	10 PPI Foam (Present study)
09:00	38	57	59
10:00	66	70	75
11:00	83	82	98
12:00	91	99	126
13:00	90	97	124
14:00	80	88	115

6.Conclusion and future work

The present study discusses experimental results obtained by comparing two box-shaped solar-cookers experienced in identical climate environments in Baghdad, Iraq. A solar cooker equipped with a 10 PPI copper-foam absorber demonstrated a stagnation temperature approximately 25.8 degrees higher compared to a box-shaped solar-cooker with a standard flat absorber. This temperature increased because more of the copper-foam absorber plate's surface area is in contact with the interior air. Additionally, the use of a 10-PPI copper-foam absorber plate resulted in a notable reduction in cooking time, up to 33%, when compared to a standard flat absorber plate. As the inclination angle increased, the mean temperatures of the 10-PPI copper-foam absorber plate also increased. The optimal internal air temperature was achieved at an inclination of 6 degrees. The cooking power equation provided an acceptable range, indicating that the solar cooker consistently cooked food and boiled water.

For optimal performance, it is recommended to employ a box-shaped solar-cooker prepared with a 10 PPI copper-foam absorber in future applications.

Acknowledgment

None.

Conflicts of interest

The authors have no conflicts of interest to declare.

Author's contribution statement

Suhaib J. Shbailat: Study conception, design, data collection, supervision, investigation on challenges and draft manuscript preparation. **Raghad Majeed Rasheed:** Data collection, conceptualization, writing – original draft, analysis and interpretation of results. **Jenan S. Sherza:** Analysis and interpretation of results, reviewing and editing. **Ansam Adil Mohammed:** Making amendments and revisions to the manuscript and linguistic modifications.

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Appendix I

S. No.	Abbreviation	Description
1	C	Effective Concentration Ratio
2	COR	Cookers Optics Thermals Ratio
3	C_p	Heat Capacity (4168 J/Kg. K)
4	DC	Direct Current
5	I	Heat Flux (W/w^2)
6	LCCM	Levelized Cost of Cooking a Meal
7	LCOC	Levelized Cost of Cooking Energy
8	LDR	Light-Dependent-Resistor
9	m	Mass Of Water (Kg)
10	MSC	Modified Solar Cookers
11	MSCIC	Modified Solar Cooker With an Inclined Cover
12	P	Cooking Power (W)
13	PCM	Phase Change Material
14	PPI	Pores Per Inch
15	P_s	The Standardized Cooking Power (W)
16	SCCs	Solar Concentrating Cookers
17	SCS	Solar Cooking System
18	T_1	Initial Water Temperature (^oc)
19	T_2	Final Water Temperature (^oc)
20	$T_{a)av}$	Average Ambient Temperature
21	TBPR	Tracking Type Bottom Parabolic Reflector
22	TES	Thermal Energy Storage
23	TPP	Thermal Performance Parameter
24	$T_{w)av}$	Average Water Temperature