مجلة اكاديمية الجبل للعلوم الاساسية والتطبيقية
Al-Jabal Academy Journal of Pure and Applied Sciences
02 (2): 01-15, 2023
pISSN: 2958-857X; eISSN: 2958-8588
Journal Homepage: https://lajak.edu.ly/journals/index.php/aajpas/index

Experimental investigation on the thermal performance of a large parabolic dish type solar cooker

Mataz Alarida[1]*, Araf Taher Almasri[2], Yousif M H Hamad[3], Yasser Aldali[4]

(1st) Department of Sustainable and Renewable Energy Engineering Faculty of Engineering Omar Al Mukhtar University

(2nd) Department of Mechanical Engineering ،Faculty of Engineering, Tobruk University,

(3rd) Department of Mechanical Engineering Faculty of Engineering Omar Al Mukhtar University,

(4th) Department of Mechanical Engineering, Faculty of Engineering, University of Derna,

DOI:

KEYWORDS:

Parabolic Dish Solar Cooker
Energy Analysis
Exergy Analysis
Thermal Behavior

A B S T R A C T:

This study investigates the performance of a parabolic dish solar cooker under local climatic conditions in Derna, Libya, with a focus on energy and exergy analyses. The experimental setup involved testing with a 13.1 kg glycerine load on January 24, 2023, under an average ambient temperature of 21.4 °C and varying solar radiation conditions. The cooker's thermal behaviour, including outer pot wall temperatures, glycerin temperature, energy and exergy rates, energy and exergy efficiencies, and heat loss factors, were monitored throughout the experiment. Results indicate that the solar cooker achieved peak solar radiation of 1043 W/m², contributing to rapid glycerin temperature rise to a maximum of 206.1°C. Energy and exergy efficiencies ranged from 0.69 to 0.008 and exhibited dependency on solar radiation and ambient temperature fluctuations. The highest heat loss factor recorded was 124.5W/K, influenced significantly by wind speed variations. This research contributes valuable insights into the operational dynamics of parabolic dish solar cookers under specific climatic conditions, offering pathways for improving their efficiency and reliability for sustainable cooking applications.

التحقيق التجريبي على الأداء الحراري لمطباق شمسي من نوع الطبق المكافئ الكبير

الكلمات المفتاحية:
طباخ الطبق المكافئ
تحليل الطاقة
تحليل exergy
السلوك الحراري

المستخلص: تتناول هذه الدراسة اداء طباخ الاطباق الشمسية المكافئ في ظل الظروف المناخية المحلية في دينا، ليبيا، مع التركيز على تحليلات الطاقة والامتداد. تم إجراء الاختبار باستخدام حمولة الغليسيرين التي تزن 13.1 كجم في 24 يناير 2023، تحت درجة حرارة محيطة متوسطة تبلغ 21.4 درجة مئوية وظروف إشعاع شمسي متغيرة. تمت مراقبة السلوك الحراري للمطبخ، بما في ذلك درجات حرارة جدار الوعاء الخارجي، ودرجة حرارة الجلسرين، ومعدلات الطاقة، وكفاءة الطاقة، وعوامل فقدان الحرارة طوال فترة التجربة. تشير النتائج إلى أن طباخ الطاقة الشمسية حقق ذروة الإشعاع الشمسي بمقدار 1043 واط/متر مربع، مما ساهم في ارتفاع درجة حرارة الجلسرين بسرعة إلى 206.1 درجة مئوية كحد أقصى. تراوحت كفاءة الطاقة من 0.69 إلى 0.008، مما يدل على اعتمادها على الإشعاع الشمسي وتقلبات درجة الحرارة المحيطة. كان أعلى عامل فقدان الحرارة المسجل 124.5 واط/كلفن، والذي تأثر بشكل كبير بتغيرات سرعة الرياح. يساهم هذا البحث في تقديم رؤى قيمة حول الديناميات التشغيلية لمطبقات الطاقة الشمسية الأطباق المكافئة في ظل ظروف مناخية محددة، مما يوفر مسارات لتحسين كفاءتها وموثوقيتها لتطبيقات الطهي المستدامة.

*Corresponding author:E-mail addresses: y.aldali@uod.edu.ly

INTRODUCTION

A solar cooker is a straightforward and environmentally friendly technology that harnesses the sun's light to cook food and heat water without producing any emissions. Unlike photovoltaic cells, which transform solar energy into electrical energy, this device directly transforms solar energy into heat for the purpose of cooking. The popularity of solar cookers has increased significantly in the past 50 years due to their affordability and effectiveness. Although there are expensive and intricate large-scale cookers designed to prepare meals for hundreds of individuals, most of the solar cookers currently in use are simple and low-tech devices. Due to the absence of fuel and operational expenses associated with solar cookers, various non-profit and humanitarian organizations, including the United Nations, are advocating for their utilization and urging citizens to harness this abundant and cost-free energy source. If solar cooking is appropriately modified, it can greatly reduce the cost of living and deforestation, while also preserving and protecting our environment and mitigating the adverse effects of global warming(Öztürk, 2004).

A plethora of African nations have obstacles in terms of both development and environmental sustainability. Firewood is frequently used as the main energy source in rural regions, which results in deforestation and environmental damage. Moreover, the utilization of fossil fuels such as kerosene and gas can have adverse consequences on both the environment and human health as a result of emissions produced during burning.

In order to mitigate the adverse effects of utilizing forest trees for charcoal manufacture and cooking, it is imperative to advocate for sustainable measures such as selective logging, replanting, and the use of energy-efficient stoves. Promoting alternate fuel sources, such as environmentally friendly and sustainable energy solutions, can also contribute to diminishing the dependence on wood and charcoal as the main cooking fuels. In addition, the implementation of legislation and monitoring methods can be essential in safeguarding forests and their ecosystems by promoting sustainable harvesting techniques and deterring illicit logging.

It is important to highlight that numerous fires in the Green Mountain region in Libya were a result of human activity. The local population primarily engaged in cutting down forest trees and igniting them for cooking purposes. Unfortunately, this practice resulted in a significant number of devastating fires that caused extensive damage to the environment, leading to habitat destruction and a loss of biodiversity. Biological, soil erosion, and air pollution are factors that contribute to climate change by releasing carbon emissions (Alharathy, 19/03/2018).

Cooking exerts a substantial level of energy consumption within the residential sector globally, with a special emphasis on impoverished nations. Cooking energy requirements constitute approximately 30% of the overall energy use in several emerging nations. Due to limited energy resources and the necessity to combat extensive deforestation in these nations, there is a demand for affordable and environmentally friendly cooking methods that utilize renewable energies (Mullick, Kandpal, & Saxena, 1987). In 1894, the concept of solar cooking was employed in China to cook ducks. In the 1940s, Dr. Maria Telkes did research in the United States on many types of sun cookers, including those that utilized heat-storing chemicals. In 1945, an Indian inventor named M. K. Ghosh created the initial solar cooker, which took the form of a box-shaped industrial item. In 1979, Marshall Longvin conducted an experiment on water pasteurization using a solar cooker (Herez, Ramadan, & Khaled, 2018). The study conducted by Mullick et al. in 1987 yielded highly favorable results regarding the thermal efficiency of solar cookers (Funk, 2000).]. In 2000, Funk advocated for the establishment of an international benchmark for evaluating solar cookers (Funk, 2000) (Farooqui, 2013). The generated solar cooker performance curve proved to be a valuable asset. The historical context of the solar cooker is depicted in Table

1.

Table 1Timeline covering the historical development of solar cooker technology, from 1830 to 2000.

Table:(1). Timeline covering the historical development of solar cooker technology, from 1830 to 2000.

year	The occurrence
1830	Horace de Sauaaure ; Solar box cooker (Swiss).
1830	Sir John Herschel ; Insulated box cooker (South Africa).
1945	Mr. M .K. Ghosh ; Solar box cooker (India).
1950	Mr. M.I. Ghai; Solar parabolic cooker (India).
2000	Solar cookers started to be tested internationally; Dr. Paul Funk suggested a universal standard for testing.

Lifang Li et al. (Li & Dubowsky, 2011) developed yet another concept for designing and building a huge parabolic dish. Reflectors were made of thin, flat metal plates having a high reflective surface. A few thin layers that were attached to the mirror petals' reverse side evolved into reflecting petals that formed a parabola when their one end was drawn towards the other by connections or cables.

According to Ibrahim et al. (Mohammed, 2012), a parabolic-dish water heater for home water heating has been developed. Assuming that each family member requires 10 liters of hot water per day, he found that the water heater supplies 40 liters of heated water per day for a household of four. Based on the outline, he first expected warm efficiencies of 50%; nonetheless, he was given warm efficiencies that were higher than the usual expected values, ranging from 52% to 56%.

Fareed. M. Mohamed et. al (Mohamed, Jassim, Mahmood, & Ahmed, 2012) When looked at the Versatile Solar Dish Concentrator, they found that a 1.6-meter-diameter solar dish collector had been planned and made, and solar steam had been generated. The dish was constructed from galvanized steel, and a receiver is positioned on the focus. The interior surface of the dish is protected by a reflective layer with a reflectivity of up to 76%. The dish is equipped with a tracking mechanism, a temperature estimation, and solar power. At midday, the output of the framework increased by 30% while the water temperature increased to 80°C.

A small-scale parabolic solar dish thermoelectric generator experiment was carried out by Eswaramoorthy et al. (Eswaramoorthy, Shanmugam, & Veerappan, 2013). They made a parabolic solar dish reflector by connecting a cleaned aluminium sheet as the concentrator surface to a discarded satellite dish receiving wire. Concentrated radiation and a water-cooled warm sink were the main sources of power generation; they considered a variety of operating parameters, such as collector plate temperature, control yield, and productivity with regard to solar radiation. The research revealed that the main factor affecting the power output was the temperature of the collector plate. Ibrahim Ladan Mohammed (Mohammed, 2013) designed and constructed a thermal cooker with a parabolic-shaped dish. The cooker was designed to prepare meals for a typical medium-sized family, such as 12 kg of dry rice every day. A direct actuator (super jack) was chosen since the concept needed the parabolic cooker to track the sun frequently for compelling implementation. Results from preliminary tests show that the solar thermal cooker's general operation was satisfactory. The cooker was capable of cooking 3.0 kg of rice in 90 to 100 minutes, which is exactly 91 minutes as predicted.

Yadav et al. (Yadav & Kumar, 2013) studied the parabolic trough collector system with multiple reflectors for a solar-powered air heater. In this experiment, the absorber tube, which was positioned in the middle of the parabolic trough, was the focal point of the reflected radiations. Air was used in this setup as the working fluid to gather heat from the absorber. He conducted his research using three different reflectors, and they discovered that aluminum sheet performs astonishingly well as a reflector when compared to steel sheet and aluminum foil.

Vardhan et al. (Patil) investigate in Bhopal (M.P.) in India, the performance of a parabolic dish collector over several seasons. They also disclosed the influence of meteorological factors on the operation of the parabolic dish collector, including Direct Normal Irradiance (DNI), wind, ambient air temperature, and humidity. The receiver is placed in this system's focal plane between the parabolic concentrator's typical design and the sun. The collector for this system has a theoretical temperature limit of 65°C. This study had an impact on the placement of small solar collectors in several parts of Bhopal.

Sakhare et al. (Sakhare & Kapatkar, 2014) developed a line focus collector with a copper tube receiver that rotates into the shape of a helical coil at the focus position. They used an experimental setup with water as the working fluid to study the performance of the collector. The highly reflective aluminium foil sheet used in this system's reflector has a reflectance factor of 0.8. The effectiveness of the collection is observed in this experiment, which is conducted in an open setting. The outcome of this method provides better indications for steam generation in rural applications. The receiver's (copper tube) helix is 22 cm in diameter and contains 15 twists. The solar tracking in an east-west direction is eliminated as a result of the receiver being positioned in the solar trace path. This experiment is run during the summer on clear days. A maximum temperature of 215°C and a steam conversion efficiency of 60–70% are the results.

Arunachala U. C. et. Al (Arunachala, Jhalaria, & Sheikh, 2014) investigated and analyze the performance of solar cookers for night cooking. They employ a CPC-based solar cooker, and this system is routinely tested for six days. Oil is utilised in this, and it can reach a maximum temperature of 110°C. Oil was measured at 35°C when the sun was not shining. Various limiting restrictions prevent the system from operating at its maximum efficiency. It has been discovered that the temperature of the oil may cook rice at noon and warm supper at night.

Arunachala U. C. et. Al investigated and analyze the performance of solar cookers for night cooking. They employ a CPC-based solar cooker, and this system is routinely tested for six days. Oil is utilised in this, and it can reach a maximum temperature of 1100C. Oil was measured at 35°C when the sun was not shining. Various limiting restrictions prevent the system from operating at its maximum efficiency. It has been discovered that the temperature of the oil may cook rice at noon and warm supper at night.

(Agrawal & Yadav, 2015) conducted a study on a solar cooker equipped with a heat storing mechanism. In theory, parabolic dish type cookers utilize sensible heat storage elements, such as sand, iron grits, stone pebbles, and iron balls, for cooking in the evening. In this theoretical inquiry, thermodynamic equations were utilized to calculate the heat absorbed and released, while various losses were quantified. The discrepancy was determined by contrasting the hypothetical data with the empirical data. A mere 9% disparity between the theoretical and practical efficiency was observed.

(Gavisiddesha, Revenkar, & Gorawar, 2013) created a parabolic solar cooker and tested it to determine that the low efficiency is solely due to losses in the reflector and receiver. Because exergy radiation is high and may be used at low temperatures, the exergy efficiency of this solar cooker varies. A cylindrical aluminium or copper vessel painted black is preferable for excellent cooking efficiency. This sort of parabolic solar dish cooker is quite useful in combating deforestation. The usage of this sort of energy also reduces pollution caused by the use of conventional energy sources for many types of home and industrial uses.

CHALLENGES OF SOLAR COOKING IN LIBYA

In this study, solar cooking was suggested as a practical way to address the worldwide issue of pollution and forest fires, namely in Africa and Libya. The aim is to replace the restricted energy supply used for cooking in households and businesses. In their study, Wentzel and Pouris (2007) (Vetter, 2006), found that solar cookers in South Africa did not achieve the expected level of usage. However, they did lead to certain cost reductions. The GTZ/DME solar cooker field test in South Africa highlighted the advantages of employing solar cookers, including fuel, monetary, and time savings. Commercializing solar cookers in Africa faces numerous challenges. This is due to the novelty of the technology, which may deter those with minimal means (as is the case for the majority of Africans) from assuming financial risks. Despite the implementation of numerous media and government initiatives, the utilization of solar cookers in Africa continues to be significantly limited. Despite the abundant sunlight and ongoing commercialization efforts, investors still lack confidence in these systems (Wentzel & Pouris, 2007). The GTZ/DME solar cooker experiment conducted in South Africa demonstrated that the utilization rate of solar cookers in the country may be improved. This finding is applicable to other African nations as well (Vetter, 2006).

Implementing solar cooking in Libya will have a positive environmental impact by decreasing harmful emissions and minimizing environmental pollution. Implementing solar cooking in Libya will significantly benefit the environment by mitigating polluting emissions, curbing deforestation for charcoal manufacturing, and reducing the risk of forest fires, particularly in the Green Mountain region.

However, the implementation of this technology will face additional challenges, one of which being the reliance of solar cooking on direct sunshine for optimal efficiency. Libya's prominent position as a petroleum producer ensures that fossil fuels are easily obtainable and exceptionally cost-effective. The cost and limited availability of conventional cooking fuels may discourage individuals from experimenting with alternative cooking methods such as solar cooking.

THE POTENTIAL OF SOLAR ENERGY IN LIBYA

There are several compelling justifications for implementing concentrated solar power in Libya. Firstly, the country benefits from a substantial influx of solar energy.

Secondly, there is ample space accessible for the installation of solar power infrastructure. Libya is situated in the center region of North Africa, covering an expansive area of 1,750,000 square kilometers. Over 85% of its territory is classified as desert. Approximately 88% of Libya's territory consists of desert, with the majority of this expanse situated in the central region known as the Sunbelt. The country has a high abundance of solar radiation, with an average daily radiation of 7.5kWh/m^2/day in the southern region and 6kWh/m^2/day in the coastal region. The annual sunlight hours exceed 3500 hours. **Figure: (1)** illustrates the dispersion of average yearly direct normal irradiance (DNI) over Libya and the North Africa region ("Average direct normal irradiation (DNI) in Libya ").

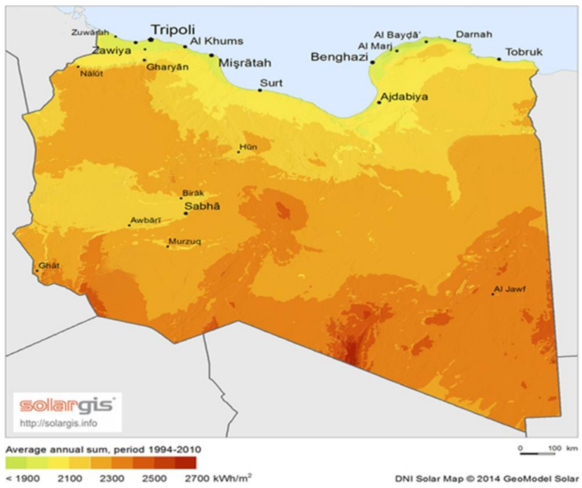

Figure: (1). Average direct normal irradiation (DNI) in Libya ("Average direct normal irradiation (DNI) in Libya ").

SOLAR COOKER SYSTEM

PARABOLIC DISH CONCENTRATOR

A parabolic dish consists of a metallic reflector in the shape of a parabola, often made of aluminum. A parabolic reflector is a surface that is used to gather or redirect energy, such as light, sound, or radio waves. The form of the object is a circular parabolic shape, resulting from the rotation of a parabola around its axis. A plane wave coming along the axis is converted into a converging spherical wave, which is concentrated at a specific spot by the parabolic reflector. A point source at the focus generates a spherical wave that is then transformed into a collimated beam, resembling a plane wave, propagating along the axis. Parabolic reflectors are utilized to gather energy from a remote source, such as the sun, and concentrate it onto a central point, thereby rectifying the spherical aberration noticed in less complex spherical reflectors. Due to the reversible nature of reflection principles, parabolic reflectors have the ability to project the energy of a source in a parallel beam outward from its focus. This property is utilized in spotlights and automotive headlights. The Aluminum parabolic solar dish collector, created as part of this research, has a geometric concentration ratio of 9.27. The parabolic dish solar concentrator imposes a constraint on the overall size of the concentrator system.

A dish of 2.2 meters in diameter was selected, with a focal length of 1 meter and a rim angle of 57.6 degrees. The solar collector system was constructed by hand utilizing small mirror pieces. Specifically, 37 triangles were created with an apex angle of 18 degrees and a thickness of 0.8 mm. These triangles were then assembled together to create a seamless solar collector shape.

CONCENTRATOR DESIGN ANALYSIS

The parabolic form of the collector is crucial for ensuring the proper functioning of the prototype. Any inaccuracies in the geometric computation would cause the solar rays to deviate, resulting in the lack of temperature at the focus point and, subsequently, reduced thermal efficiency. A mathematical analysis was undertaken to find the parabola by identifying the values that satisfy the stated design criteria, including diameter, rim angle, and concentration ratio. The investigation employs the scheme illustrated in **Figure: (2)**.

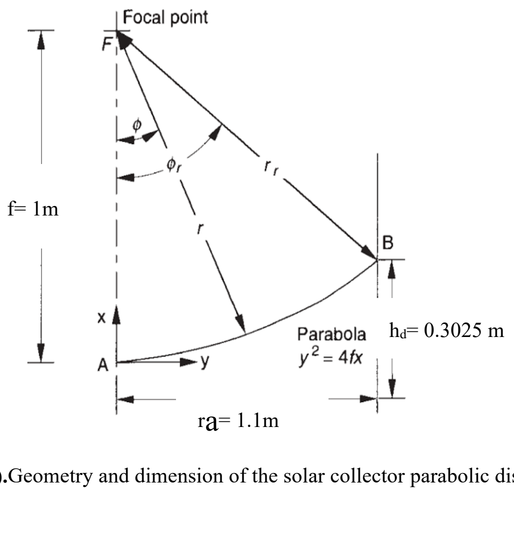

Figure: (2). Geometry and dimension of the solar collector parabolic dish.

- Parabolic dish radius (ra = 1.1m)
- Parabolic dish depth (hd = 0.3025 m)

The value of focal length can be calculated

$$Y^2 = 4fx \qquad (1)$$

To calculate the rim angle from the equation (2)

$$tan\left(\frac{\psi}{2}\right) = \frac{D_a}{4f} \quad (2)$$

ψ = 57.6°

The area of the receiver *Ar*

$$Ar = \frac{\pi * D^2}{4} \quad (3)$$

$Ar = 3.801\ m^2$

Table: (2). Dimensions and thermo-physical properties of all system.

Parameter	Value
Parabolic dish	
Concentrator diameter	2.2 m
Focal distance	1 m
Depth of the parabola	0.3025 m
Rim angle	57.6°
Collector aperture area	3.801 m^2
Concentration ratio	9.27
Cooking pot	
Pot diameter	0.32 m
Pot height	0.25m
Surface area of the pot	0.41m^2
Thickness	2 mm
Mass of cooking pot	3.92 kg
Mass of Glycerin in the cooking pot	13.2 kg
Specific heat of Glycerin	3014J/kg.K
Specific heat of cooking pot	904 J/kg.K

RECEIVER AREA

This is the focal point where the reflector will converge all of the sun radiation. The parabolic reflector, positioned precisely at the focal point, firmly establishes the receiving region. If the cooking device is positioned in close proximity or at a significant distance from the focal point, the cooker will not function.

COOKING POT

In order to transform light into heat, it is necessary for the cooking device to have a dark hue and be positioned near the focal point to maximize the absorption of reflected rays. **Figure: (3)** depicts a cooking pot dimensions.

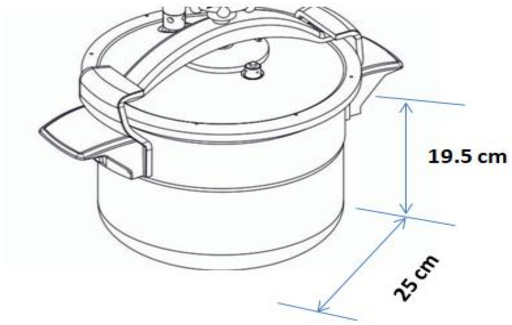

Figure: (3).cooking pot dimensions.

EXPERIMENTAL TEST PROCEDURE

An experiment was carried out using a Parabolic Cooker (PC) in the climate conditions of Darnah city on January 24, 2023. The PC and cooking pot were allowed to warm up so that, on a given test day at an experimental location, they were in thermal equilibrium with the local weather conditions before the experimental test began. By doing this, the test load—glycerin—is heated without having to undergo a cold start.

Under clear sun, the glycerin-filled cooking pot was heated with the proper manual PC tracking. The cooking pot filled with glycerin absorbs and reflects the solar flux that falls on the PC's reflector in its focus region. Thus, as the experiments progress, the temperature of glycerin rises quickly and then appears to stagnate. Since the PC is an open system, heat losses are to be expected.

To determine the PC's thermal performance at the experimental site, field tests were carried out during the window of solar noon, ± 120 minutes of solar noon.

In our study, data logger recorded T_f, T_a, T_{wall}, and G at a consistent interval of 2 minutes during the test.

A calibrated K-type thermocouple was used to measure the temperature. It was inserted at the center of the glycerin, away from the bottom of the pot, through a hole in the middle of the cooker or cooking pot top. The aperture was securely closed to prevent the emission of vapor.

Thermocouples were positioned on the lid and cylindrical surface of the pot to observe the increase in temperature of the exterior body of the cooker. The sun radiation G was recorded at 2-minute intervals. The measurement was conducted by recording the radiation value that was incident on a plane perpendicular to the direction of the radiation beam. This corresponds to the highest magnitude of solar flux in that specific direction.

A Research pyranometer was utilized to quantify the entirety of solar radiation. The trials were conducted within a time frame of plus or minus 2 hours from solar noon.

METHODS FOR ENERGETIC AND EXERGETIC ANALYSIS

Cuce& Cuce (Cuce & Cuce, 2013) provides the energy input rate Ei to the cooker.;

$$E_i = G * A \qquad (4)$$

where A is the cooker's aperture area and G is the instantaneous solar radiation.

The exergy rate of solar radiation, denoted as E_{xi}, for the solar cookers may be determined using the Petela formula (Petela, 2005)

$$E_{xi} = G * \left[1 + \frac{1}{3} * \left(\frac{T_a}{T_s}\right)^4 - \frac{3*T_a}{4*T_s}\right] * A \qquad (5)$$

Petela (Petela, 2005) defines the ambient temperature as Ta and the surface temperature of the sun as Ts, which is measured at 5778 K.

The pace at which the temperature of the water inside the cooking pot rises as it absorbs heat from the aperture area is the cooker's instantaneous output energy rate, or E_o. The following symbol represents the value (Cuce & Cuce, 2013):

$$E_o = \frac{m*c*(T_f - T_i)}{\Delta t} \qquad (6)$$

The following variables were included in this experiment: Tf is the final glycerin temperature recorded at each time interval, Ti is the starting glycerin temperature in each cooker, m is the mass of the water, and c is the specific heat capacity of glycerin. To calculate the immediate output, the cooker's exergy analysis considers the surrounding temperature. The cooker's exergy rate, or Exo, can be written as follows (Cuce & Cuce, 2013):

$$E_{xo} = \frac{m*c*(T_f - T_i) - m*c*T_a*\ln\left(\frac{T_f}{T_i}\right)}{\Delta t} \qquad (7)$$

The energy efficiency of the cooker is thus given as (Cuce & Cuce, 2013):

$$\eta_e = \frac{E_o}{E_i} \qquad (8)$$

and Cuce & Cuce (2013) provide the cooker's energy efficiency:

$$\eta_{ex} = \frac{E_{xo}}{E_{xi}} \qquad (9)$$

Thus, the following formula can be used for estimating the instantaneous heat loss factor at each time period in W/K:

$$U_L' = \frac{E_i - E_o}{T_{wall,av} - T_a} \quad (10)$$

where U_L^' is the heat loss factor and T_(wall,av) is the average wall temperature as measured by the four thermocouples at the pot's walls.

RESULT AND DISCUSSION EXPERIMENTAL UNCERTAINTY

To determine the accuracy of the main experimental findings that might be impacted by frequent errors that frequently occurred during the testing period, an uncertainty evaluation process was carried out. Measured variables have a rapid influence on the uncertainty analysis regarding the solar cooker thermal efficiency estimate. Both are thought of as these intended measurable parameters, T_f and G. Equation only estimates the standard uncertainty (u) for solar cooker systems under the reasonable assumption that all of these observed parameters have a uniform distribution.

Where the accuracy of the experimental instrument is represented by (a) and its accuracy is denoted by (u). The table lists the experimental instruments together with their standard uncertainties.

Table: (3). Standard uncertainties, accuracy, and experimental equipment.

Instrument	Unit	Accuracy	Standard Uncertainty
RK200-03 pyranometer	W/m^2	$\pm 0.02\ W/m^2$	$1.15\times10^{-2}\ W/m^2$
K-type thermocouples	C°	$\pm 0.1\ C^{\circ}$	$5.7\times10^{-2}\ C^{\circ}$

During an evaluation process, the least-square fit analysis was utilized to determine the degree of uncertainty in the calculated efficiency resulting from specific uncertainties related to each tested parameter. As a result, (Elminshawy, Mohamed, Morad, Elhenawy, & Alrobaian, 2019)determines it using the following expression:

$$W\eta = \left[\left(\frac{\partial\eta}{\partial_t}\right)^2 (u_t)^2 + \left(\frac{\partial\eta}{\partial_{G_T}}\right)^2 (u_{G_T})^2\right]^{\frac{1}{2}} \quad (11)$$

After calculation, the highest approximate uncertainty of the CSC is estimated to be around ± 0.57%.

TEMPERATURE AND SOLAR RADIATION PROFILES

The figures below indicate the outcomes of the experimental test with a 13.1 kg load. The date of this experimental test was January 24, 2023. In the experimental test, the average ambient temperature was 21.4 °C. Throughout the testing period, the average wind speed, which came from the northwest, ranged between 1 and 2 m/s. The global solar radiation fluctuation with respect to local time is depicted in **Figure: (4)**. The experiment ran from approximately 10:40 a.m. to 14:40 p.m. At the onset of the experiment, the solar radiation was 990 W/m^2, and it increased gradually until reaching a peak of approximately 1043 W/m^2 at 12:10 h local time. The change in solar radiation indicates a fairly clear sky condition; small decreases in solar radiation could be due to sunlight passing through clouds.

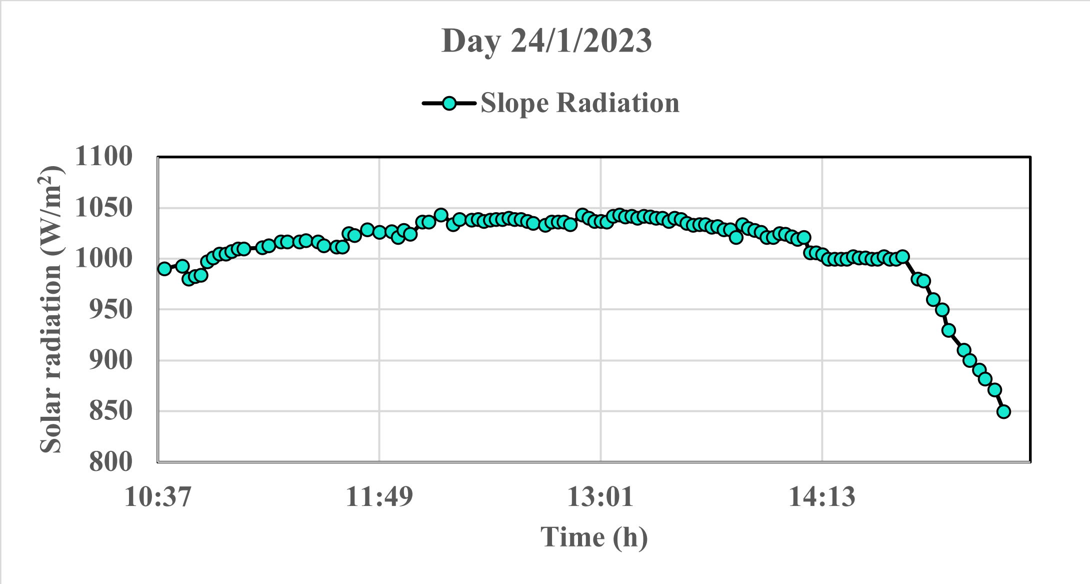

Figure: (4). Slope solar radiation.

The plot in **Figure: (5)**displays the cooking pot's exterior wall temperatures for the cooker. As the experiment carried on, the cooker's wall temperatures gradually increased. Since the left side of the cooking pot was facing east, the direction of the sun, the left side's wall temperature is slightly higher than the right side's.

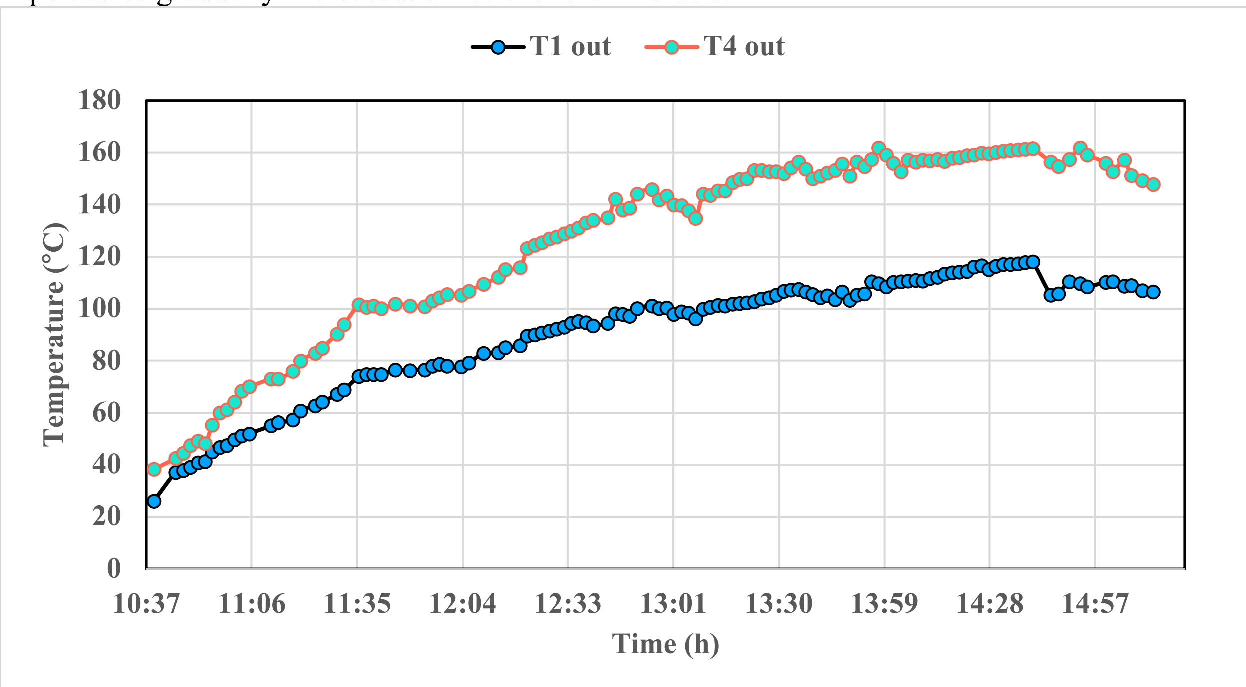

Figure: (5). Outer wall pot temperature, the left side of the pot is labeled as T4out and the right side as T1out.

Figure: (5)displays the internal glycerin temperature of the cooker, along with the temperature of the surrounding air. Throughout the experimental trial, the mean ambient temperature recorded was 21.3 °C. Due to the high intensity of solar radiation, the temperature of the glycerin in the cooking pot rose. The glycerin took 60 minutes to reach a temperature of 146.6 °C under normal conditions. The experiment concluded with a rise in the maximum temperature to 206.1 °C at 2:40 h and a final temperature of 201 °C at 3:13

h. At at 1:02 a.m., the quasi-steady state started. The manual tracking of the parabolic dish cooker, which makes sure that only the direct component of solar radiation is used to direct maximum solar radiation onto the cooking pot, may be connected to the variations in the steady-state condition of the glycerin temperature.

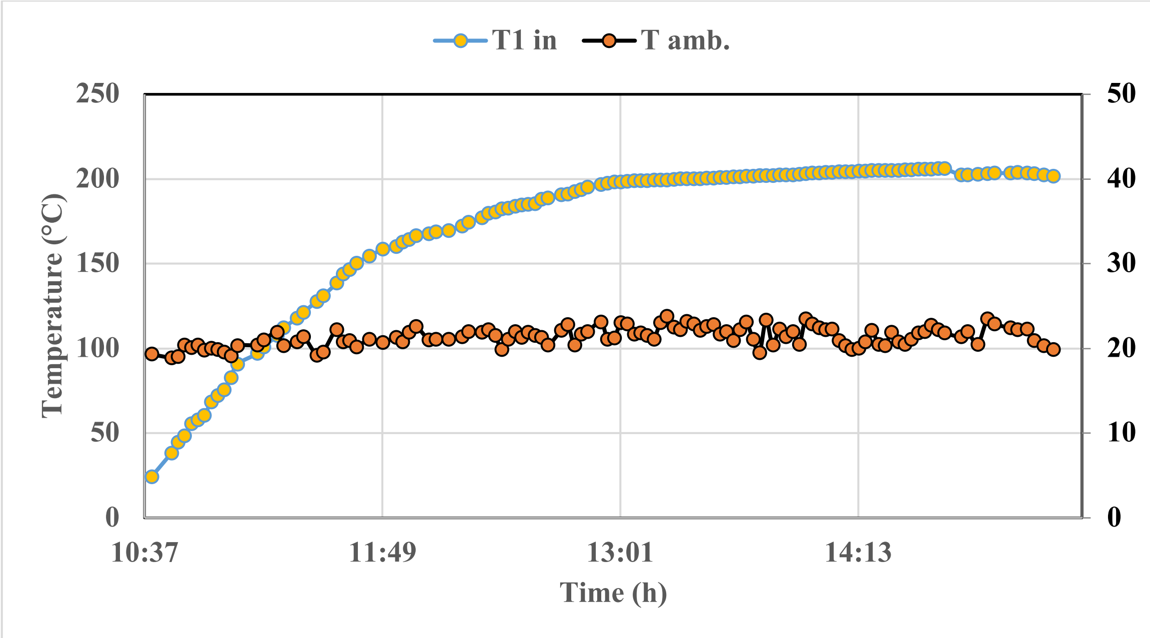

Figure: (6). The ambient temperatures and the glycerin temperatures, the ambient temperature is labeled as Tamb and the glycerin temperature is T1 in.

ENERGY AND EXERGY FOR THE SOLAR COOKER

Figure (7) shows the energy rate (power) for the parabolic solar cooker. The parabolic solar cooker has the largest initial energy rate, around 2685.47 W, which decreases to 33.1 W at the end of the experiment. The greater amount of focused solar radiation surrounding the pot may have caused the glycerin temperature to rise to the steady-state condition rapidly, which is responsible for the higher initial energy rate and faster decline. The manual tracking procedure of the plate is the cause of the power rate values fluctuations.

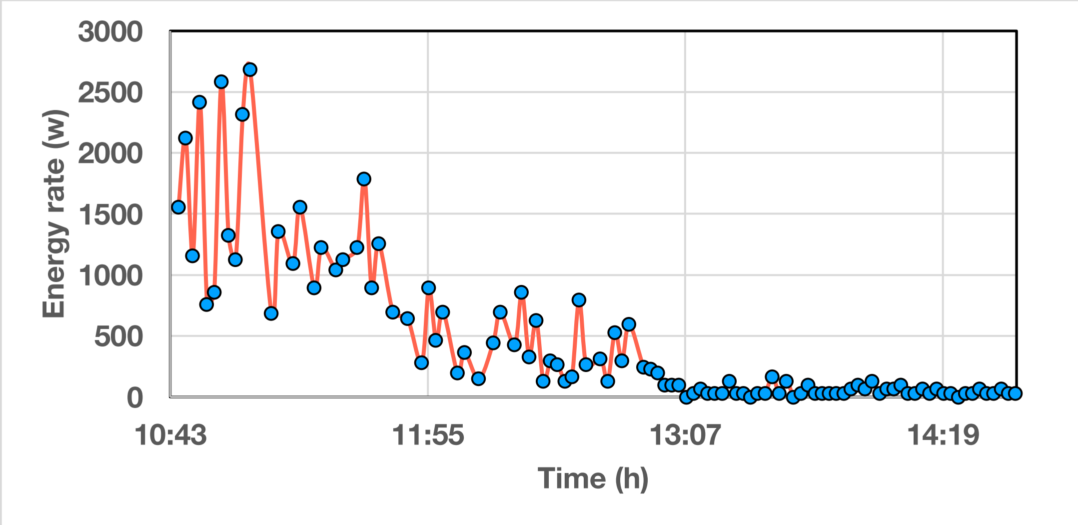

Figure: (7). Energy output rate for the solar cooker.

The energy efficiency of the parabolic dish solar cooker gradually declines over time when subjected to ambient weather conditions, starting at 0.69 and reaching approximately 0.008 by the end of the experiment. This signifies a notable increase in heat losses, which escalate from 31.1% to 99.2% over the course of cooking.

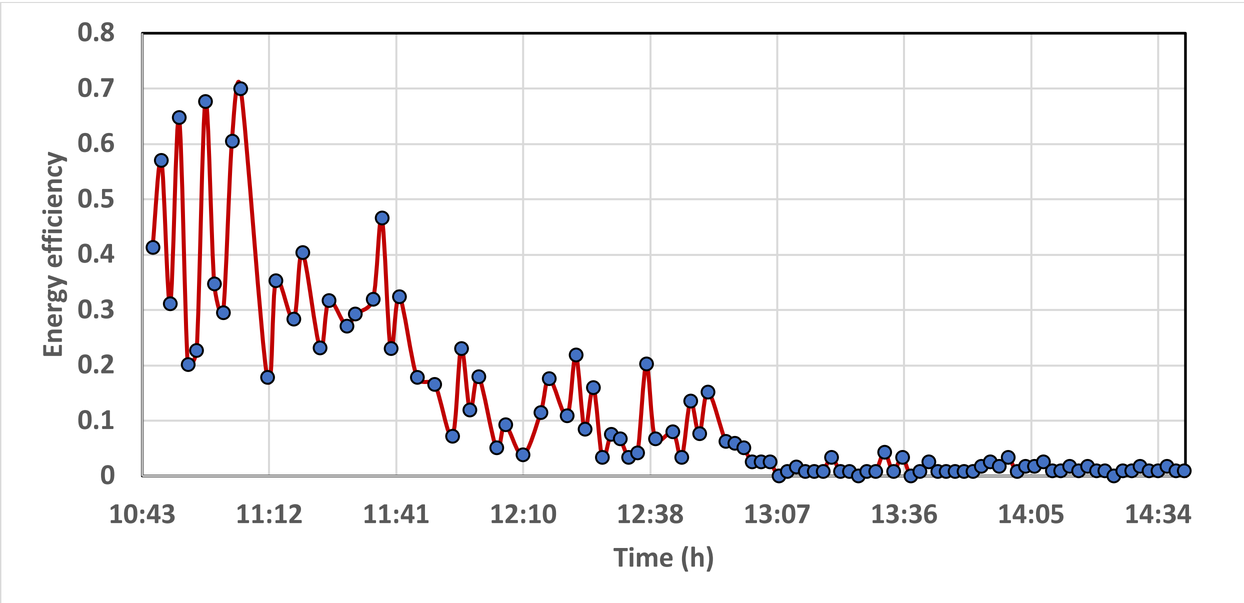

Figure: (8). Energy efficiency for the solar cooker.

Figure: (8)presents the energy rate findings with a 13.1 kg glycerin load. Due to the inclusion of heat losses, the energy rate values are significantly greater than those of the energy rate. The exergy rate values exhibit swings that align with the variations in ambient temperature depicted in Figure 4.3. Therefore, we can infer that the exergy rate values are greatly affected by the ambient temperature. The exergy rate value graphs exhibit the same pattern of both decline and increase. The parabolic solar cooker experiences a significant rise in glycerin temperature, leading to an exergy value of roughly 520.2 W due to the higher concentration of solar energy. Like energy rates, the exergy rate of the parabolic solar cooker has a sharp decline after 12:52 hours. The energy and energy rate fluctuations with respect to local time demonstrate the variations observed over the experimental period. The average results obtained throughout the entire trial period offer a more concise and comprehensive perspective on the relationship between glycerin load and energy levels and rates.

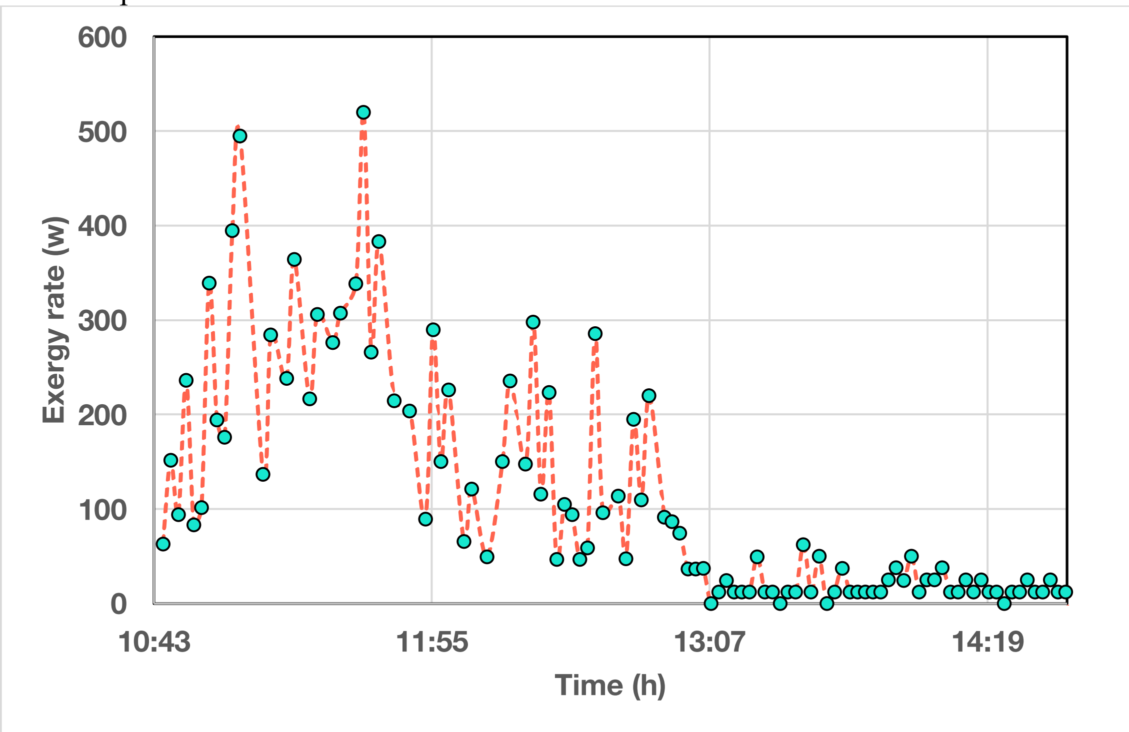

Figure: (9). Exergy output rate for the solar cooker.

Figure: (9)'s energy efficiency shows a similar range of variance to that of the exergy rates. At the beginning of the trial, the parabolic dish cooker is subjected to the surrounding environment. displayed quite high exergy efficiency. The exergy efficiency value at its maximum is 0.14.

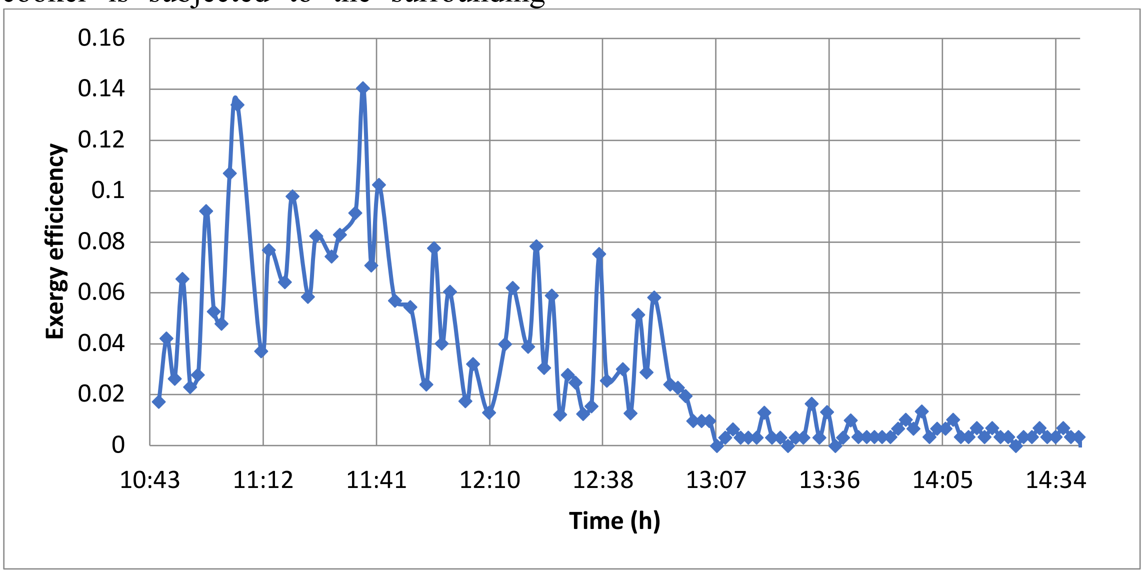

Figure: (10). Exergy efficiency for the solar cooker.

Figure: (10) shows the estimated instantaneous heat loss factor for the parabolic dish solar cooker. The solar cooker that remains outside shows high heat loss factor values. After the glycerin temperature raises rapidly, the heat loss factor values decrease and fluctuate until they reach a final value of about 30 W/K, where they tend to display a constant increase. At 10:54 hours, the heat loss coefficient was 124.5 W/K. That was a result of the strong wind at the time.

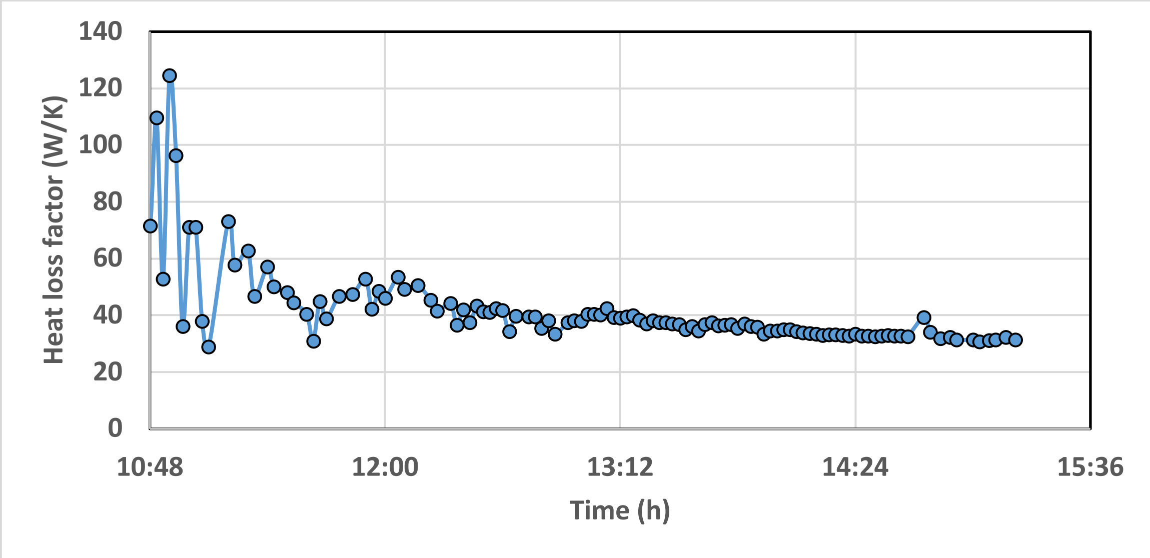

Figure: (11). The parabolic solar dish cooker's heat loss factor.

CONCLUSION

This thesis investigated the performance of a parabolic dish solar cooker under the climatic conditions of Dernah, Libya, with a specific focus on the efficiency, exergy, and heat loss factors of the system. The experimental test was conducted on January 24, 2023, with a load of 13.1 kg of glycerin.

KEY FINDINGS

1) The experiment commenced with solar radiation at 990 W/m² and peaked at 1043 W/m² around 12:10 PM, indicating a predominantly clear sky with minor fluctuations due to passing clouds.
2) The exterior wall temperatures of the cooking pot increased steadily, with the left side (facing east) slightly higher due to direct sunlight exposure.
3) The glycerin temperature within the cooker rose significantly, reaching 146.6 °C within the first hour and peaking at 206.1 °C by the end of the experiment, achieving a quasi-steady state around 1:02 PM.
4) The initial energy rate of the parabolic solar cooker was 2685.47 W, which decreased to 33.1 W by the end of the experiment. The high initial energy rate facilitated rapid heating of the glycerin.
5) Energy efficiency decreased over time from 0.69 to 0.008, reflecting increased heat losses from 31.1% to 99.2%.
6) The exergy rate peaked at 520.2 W due to concentrated solar radiation, with fluctuations mirroring ambient temperature changes.
7) The exergy efficiency reached its peak at the start of the experiment, with a value of 0.14, and exhibited a similar oscillating pattern as the exergy rate.
8) The early values of the predicted instantaneous heat loss factor were high (124.5 W/K) due to severe gusts. However, it gradually reduced over time and eventually stabilized at around 30 W/K.

The parabolic dish solar cooker exhibited a significant capacity for initial heating, swiftly elevating the temperature of the glycerin load.

Nevertheless, the system experienced substantial heat dissipation over a period, resulting in reduced energy and exergy efficiency. The variability of the exergy rates and heat loss factors highlights the influence of environmental circumstances, specifically changes in wind speed and temperature, on the system's efficiency.

REFERENCES

Agrawal, H., & Yadav, A. (2015). Design and experimental testing of solar cooker with sensible heat storage. *Journal of Energy Research and Environmental Technology, 2*(3), 200-204.

Alharathy, S. (19/03/2018). Fire rips through Green Mountain Forest. Retrieved from https://libyaobserver.ly/news/fire-rips-through-green-mountain-forest

Arunachala, U., Jhalaria, A., & Sheikh, M. (2014). Design, fabrication and performance analysis of solar cooker for night cooking. *International Journal of Renewable Energy and Environmental Engineering, 2*(4).

Average direct normal irradiation (DNI) in Libya Retrieved from https://solargis.com/maps-and-gis-data/download/libya

Cuce, E., & Cuce, P. M. (2013). A comprehensive review on solar cookers. *Applied Energy, 102*, 1399-1421.

Elminshawy, N. A., Mohamed, A., Morad, K., Elhenawy, Y., & Alrobaian, A. A. (2019). Performance of PV panel coupled with geothermal air cooling system subjected to hot climatic. *Applied Thermal Engineering, 148*, 1-9.

Eswaramoorthy, M., Shanmugam, S., & Veerappan, A. (2013). Experimental study on solar parabolic dish thermoelectric generator. *International Journal of Energy Engineering, 3*(3), 62.

Farooqui, S. (2013). A Vacuum Tube Based Improved Solar Cooker. Sustainable Energy Technologies and Assessments, 3, 33-39. In.

Funk, P. A. (2000). Evaluating the international standard procedure for testing solar cookers and reporting performance. *Solar energy, 68*(1), 1-7.

Gavisiddesha, S., Revenkar, P., & Gorawar, M. (2013). Evaluation of thermal performance of paraboloid concentrator solar cooker. *International Journal of Innovation Research in Technology & Science, 1*(3), 58-65.

Herez, A., Ramadan, M., & Khaled, M. (2018). Review on solar cooker systems: Economic and environmental study for different Lebanese scenarios. *Renewable and Sustainable Energy Reviews, 81*, 421-432.

Li, L., & Dubowsky, S. (2011). A new design approach for solar concentrating parabolic dish based on optimized flexible petals. *Mechanism and machine theory, 46*(10), 1536-1548.

Mohamed, F. M., Jassim, A. S., Mahmood, Y. H., & Ahmed, M. A. (2012). Design and study of portable solar dish concentrator. *International Journal of Recent Research and Review, 3*, 52-59.

Mohammed, I. L. (2012). Design and development of a parabolic dish solar water heater. *International Journal of Engineering Research and Applications, 2*(1), 822-830.

Mohammed, I. L. (2013). Design and development of a parabolic dish solar thermal cooker. *International Journal of Engineering Research and Applications, 3*(4), 1179-1186.

Mullick, S., Kandpal, T., & Saxena, A. (1987). Thermal test procedure for box-type solar cookers. *Solar energy, 39*(4), 353-360.

Öztürk, H. H. (2004). Experimental determination of energy and exergy efficiency of the solar parabolic-cooker. *Solar energy, 77*(1), 67-71.

Patil, S. D. K. P. S. Analysis of Parabolic Solar Dish Collector-Review.

Petela, R. (2005). Exergy analysis of the solar cylindrical-parabolic cooker. *Solar energy, 79*(3), 221-233.

Sakhare, V., & Kapatkar, V. (2014). Experimental analysis of parabolic solar dish with copper helical coil receiver. *International Journal of Innovative Research in Advanced*

Engineering (IJIRAE), 1(8), 199-204.
Vetter, H. (2006). Solar cooker project of ADES. *Madagascar Conservation & Development, 1*(1).
Wentzel, M., & Pouris, A. (2007). The development impact of solar cookers: a review of solar cooking impact research in South Africa. *Energy policy, 35*(3), 1909-1919.
Yadav, A., & Kumar, M. (2013). Experimental study and analysis of parabolic trough collector with various reflectors. *International Journal of Energy and Power Engineering, 7*(12), 1659-1663.