




Research Article

Modeling and Optimization of Solar-Powered Pyrolysis Reactor for Plastic Waste Conversion into Valuable Products

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Abstract: The conversion of plastic waste into useful fuels and chemicals can mitigate landfill accumulation while offsetting fossil-derived energy demand. This study develops a low-cost solar-thermal approach for providing the high process temperatures required for plastic pyrolysis by modelling, fabricating, and experimentally evaluating a parabolic dish concentrator integrated with solar tracking. A theoretical framework is presented for solar radiation capture, concentrator geometry, concentration ratio, and receiver heat-loss-based thermal performance, alongside efficiency metrics commonly used to assess plastic-to-oil conversion (waste-reduction efficiency, conversion efficiency, and oil recovery). A prototype parabolic dish (rim angle 45°) was designed with key geometric parameters, including a 0.61 m diameter, a 0.06 m focal point, and an estimated concentration ratio of 100, selected to accommodate low-cost reflector materials. Three reflector preferences, including a Polyethylene Terephthalate (PET) mirror, an emergency blanket, and a conventional mirror, were tested under comparable conditions using a dual-axis tracking structure. Experimental outcomes demonstrate that the dishes can achieve very high focal temperatures (up to ~ 817 °C for the emergency blanket and ~ 807 °C for the mirror configuration in the reported dataset), with maximum thermal power on the order of 361-389 W across configurations. When techno-economic indicators are included, the emergency blanket reflector exhibits the most favourable practicality, yielding the lowest mass-to-heat-power ratio ($1.04 \times 10^{-3} \text{ kg} \cdot \text{W}^{-1}$) and cost-to-heat-power ratio ($1.41 \text{ THB} \cdot \text{W}^{-1}$). These results support the feasibility of lightweight, low-cost solar concentrators as a heat source for decentralised plastic waste pyrolysis. This study provides an experimental comparison of low-cost reflective materials and identifies key design considerations for lightweight solar parabolic dish concentrators.

Keywords: solar parabolic dish concentrator, dual-axis tracking, plastic waste, pyrolysis, low-cost reflector materials, techno-economic assessment

1. Introduction

Plastic waste management is still lacking, especially in developing nations, despite the growing need for plastic.

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Low-density polyethylene, polyethylene terephthalate, high-density polyethylene, polystyrene, polypropylene, and polyvinyl chloride compose most of the plastic trash. Plastic garbage is the most common component of landfills since it takes over 500 years for it to naturally decompose (Barnes et al., 2009). The atmospheric ozone layer, which reflects or blocks hazardous solar radiation, is being damaged by NO_x, CFCs, and CO₂, which is the cause of the rise in global temperatures. Fossil fuels are a major source of greenhouse gases, and reducing their use is challenging due to economic and technological impacts. Clean, sustainable energy is essential to meet demand and combat global warming. The protection of the environment and the control of pollution are issues of paramount global concern. Consequently, researchers are increasingly focused on developing strategies to mitigate the detrimental environmental impacts of petroleum waste. The provision of clean water and the transition to renewable energy are critical and escalating challenges of the modern era. Photocatalysis has emerged as a promising technology that can address both of these issues simultaneously (Rafique et al., 2023). Access to energy derived from fossil fuels is a fundamental prerequisite for the economic development and industrialization of any nation. Solar Photovoltaics (PV) generate electricity directly, while solar thermal converts sunlight into heat. Solar thermal offers higher efficiency, lower costs, energy storage, and the ability to use alternative fuels for continuous operation (Savangvong et al., 2021). The solar collector functions as a heat exchanger by absorbing solar radiation, converting it to heat, and then transferring that heat to a fluid that travels through the collector (Gorjian et al., 2020). As seen in Figure 1, the tracking types of the solar collector technologies are non-tracking, single-axis tracking systems, and dual-axis tracking systems. The most efficient tracking system is the dual-axis one, which comprises a solar tower receiver, Parabolic Dish Concentrators (PDCs), and a linear Fresnel reflector. Figure 1a, b, and c illustrate the classification of solar thermal collector systems based on non-tracking, single-axis tracking, and dual-axis tracking configurations, respectively, providing context for the technologies examined in this work.

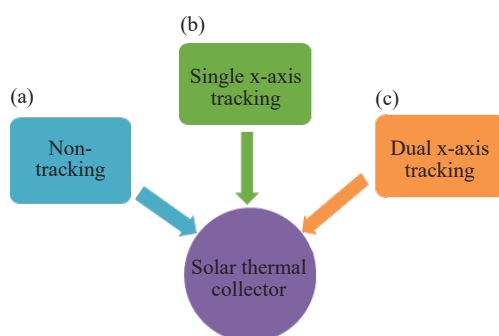


Figure 1. Classification of traditional technologies (a) non-tracking; (b) single-axis tracking; and (c) dual-axis tracking

Numerous relevant studies on the parabolic concentrator dish demonstrated how expensive and hefty the solar dishes are (Hijazi et al., 2016). To efficiently concentrate solar radiation, they require very big mirrors with nearly perfect curves. A sizable sum of money is needed to build a dish prototype for research and experimentation because the entire dish construction and the reflecting material are expensive. Thus, the purpose of this study is to determine whether it is possible to construct a solar dish system prototype at the lowest possible weight and cost while keeping the solar collector system's high efficiency. The solar energy in the current study is used to produce the required temperature to melt the plastic waste in the reactor by using the disc mirror, as shown in Figure 2 below. With the help of a disc mirror, we shall be able to concentrate the radiation at one point to produce the required heat to melt the plastic waste materials placed in the reactor. The catalyst is also used in the project to prepare the plastic melt waste at a reduced temperature; thus, it would be of much benefit in saving time in the pyrolysis process or even upgrading the efficiency of the system.

- Use of concentrated solar energy: A disc mirror focuses solar radiation at a single point to generate the temperature required to melt plastic waste in the reactor.
- Catalyst-assisted pyrolysis: The incorporation of a catalyst reduces the temperature needed for melting, saving time and improving process efficiency.

- Enhanced system efficiency: The combination of solar concentration and catalyst integration optimizes the pyrolysis process, improving overall performance.

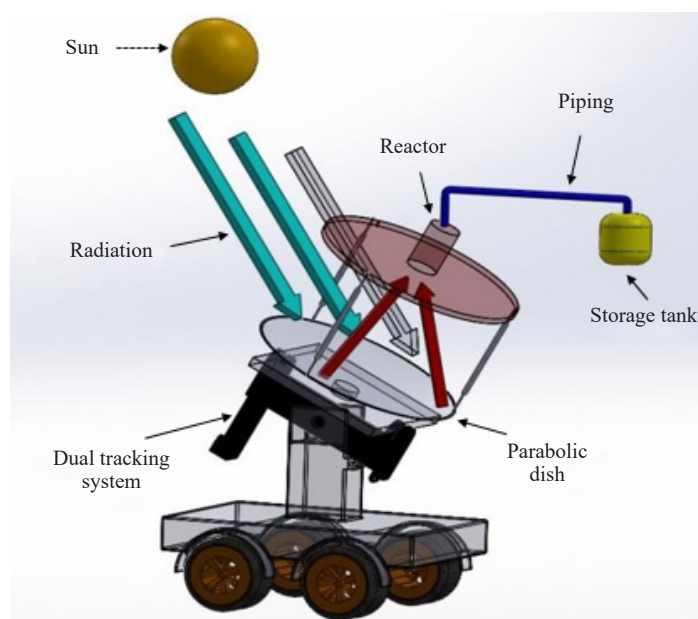


Figure 2. SolidWorks model of the pyrolysis reactor system

2. Literature review

A thorough summary of solar concentrator technologies, such as compound parabolic concentrators, Fresnel lenses, and parabolic dishes, may be found in the review by Rizwan et al. (2024). It covers the uses, design philosophies, and performance attributes of different concentrator kinds. Concentrated Solar Power (CSP) technologies, such as parabolic troughs, power towers, and dish systems, are covered in the book chapter by Alalewi (2014). Recent developments in CSP technology, design ideas, and performance measures are covered. Maatallah et al. (2025) conducted research on the design and optimisation of parabolic dish systems used to generate power. Their work focuses on tracking mechanisms, receiver configurations, and optical design to optimise energy conversion efficiency. In this comparative analysis, researchers assess how well Fresnel lens and parabolic dish systems work for CSP applications. It evaluates the cost-effectiveness, optical efficiency, and energy collection efficiency to determine the advantages and disadvantages of every kind of concentrator. The effectiveness of two-axis tracking systems for parabolic dish concentrators is assessed in the study by Lorilla and Barroca (2022). To maximise solar tracking precision and energy-collecting effectiveness, it contrasts several tracking algorithms and control approaches. Hantosh et al. (2023) studied the solar-to-electric efficiency of parabolic dish systems, analyzing optical, receiver, and conversion losses to identify performance bottlenecks and optimization opportunities. An environmental impact study of parabolic dish systems is carried out by Agostini et al. (2021), who considered waste output, greenhouse gas emissions, and resource usage. Their research assesses how CSP technologies affect sustainability. Ciulla et al. (2023) proposed a methodology for designing hybrid parabolic dish systems, combining solar, wind, and storage to optimize efficiency and reliability in off-grid locations.

A thermal analysis of parabolic dish receivers used in CSP systems is carried out by Mandhare and Sinha (2020). To increase receiver efficiency, their research looks at performance optimization techniques, receiver materials, and heat transfer methods. Aboelmaaref et al. (2020) reviewed solar tracking algorithms with an emphasis on tracking accuracy and energy collecting efficiency for parabolic dish systems. To maximize the performance of solar concentrators, it contrasts various tracking techniques, such as sun-tracking algorithms and predictive tracking algorithms. And the solar thermal desalination with parabolic dish systems to supply dry areas with fresh water. To sustainably solve the issues

posed by water shortage, it looks at desalination technologies, thermal energy storage, and system architectures. Finding high-performing and environmentally friendly materials for solar concentrator applications is the goal of their research. Pratik et al. (2024) concentrate on parabolic dish system receiver design and optimization for CSP applications. To increase total system efficiency, their research looks at receiver geometry, heat transfer fluids, and thermal performance enhancement methods. The review by Pascual et al. (2022) covers the most recent developments in the field of CSP, such as innovative collector designs, thermal energy storage devices, and ideas for hybrid power generation. To get CSP technology closer to grid integration and commercial viability, it highlights important obstacles and opportunities.

An economic feasibility analysis of parabolic dish systems for energy generation is carried out by Researchers. To determine if CSP plants are financially viable, their research analyzes investment costs, operating expenses, and revenue potential. To provide continuous energy generation during times of low solar irradiation, Gu et al. (2025) investigate thermal storage devices for parabolic dish systems. To improve the dispatchability and dependability of CSP facilities, the study examines heat transfer fluids, storage materials, and system integration strategies. The market size, growth trends, and competitive landscape of the global CSP industry are all covered in detail in Market Research Future's 2021 market report. It emphasizes new developments in technology, avenues for investment, and legislative frameworks that will influence the global deployment of CSP in the future. Researchers create computer models to mimic how parabolic dish collectors would function in various operational scenarios. Their study makes it possible to anticipate energy production and system efficiency with accuracy, which makes design optimization and performance analysis easier. Researchers investigated the thermochemical conversion of plastic waste made of Low-Density Polyethylene (LDPE) via pyrolysis-gasification procedures. To optimize energy recovery and syngas generation from plastic trash, it explores the merging of pyrolysis and gasification stages, providing a sustainable method for converting waste into energy. The pyrolysis of LDPE plastic waste using solar radiation as the heat source is examined in the work by Habtewold et al. (2020). It highlights the potential of integrating renewable energy into plastic waste valorization processes by investigating the viability of solar pyrolysis for decentralized waste-to-energy conversion. Yang et al.'s (2023) study used several catalysts to examine microwave-assisted catalytic pyrolysis of LDPE plastic waste. It examines how catalytic conversion and microwave heating work in concert to affect product yields and composition, showing how effective it may be to use both techniques to maximize the value of plastic waste. In the 2022, Wijayanti et al. (2022) explore the use of fluidized bed reactors for the pyrolysis of LDPE plastic waste. It looks at how feedstock characteristics, residence duration, and reactor temperature affect the pyrolysis process and product distribution. This helps with reactor design and optimization for effective conversion of plastic waste.

Fresneda-Cruz et al.'s (2025) study explore the use of microwave heating for the pyrolysis of LDPE plastic waste. It highlights the potential of microwave-assisted pyrolysis for effective plastic waste valorization by investigating the effects of microwave power and reaction time on product yields and quality. Thermo-Gravimetric Analysis (TGA) is used in Kplé et al.'s (2019) study to examine the pyrolysis kinetics of LDPE plastic waste. It looks at how the pyrolysis environment, reaction temperature, and heating rate affect the kinetics and behavior of LDPE breakdown, offering useful information for process modeling and optimization. Susastriawan et al.'s (2020) study focuses on the use of zeolite catalysts in the catalytic pyrolysis of LDPE plastic waste. It explores how catalyst type, loading, and reaction conditions affect the yield and makeup of pyrolysis products, highlighting how catalytic pyrolysis can lead to improved product selectivity and the creation of compounds with added value. Shukla and Neelancherry's (2021) study explores the optimization of biooil production from the microwave copyrolysis of food waste and LDPE using response surface methodology. The research examines the effects of reaction temperature, catalyst type, and residence time on the yield and quality of the resulting biooil, providing insights into the efficient and environmentally friendly valorization of plastic and organic waste. Zou et al.'s (2022) study investigates the potential synergistic benefits of co-pyrolysing LDPE plastic waste with biomass feedstocks. It illustrates the promise of co-pyrolysis techniques for improved resource recovery and product value by examining the effects of feedstock ratios, reaction conditions, and catalysts on product yields and attributes. Muhammed (2024) evaluated the economic feasibility of solar pyrolysis systems that use concentrated parabolic dish technology to value plastic waste. It examines how cost-effectively various temperature ranges work in terms of initial investment, ongoing costs, and product value, offering valuable information about the sustainability of solar-powered plastic waste treatment. Maytorena and Buentello-Montoya (2024) examined the energy efficiency of solar pyrolysis systems that use focused parabolic dish technology to value plastic waste. It analyses the system's thermal performance throughout a range of temperatures and measures the overall energy conversion efficiency,

offering valuable information about the sustainability and practicality of treating plastic trash using solar power.

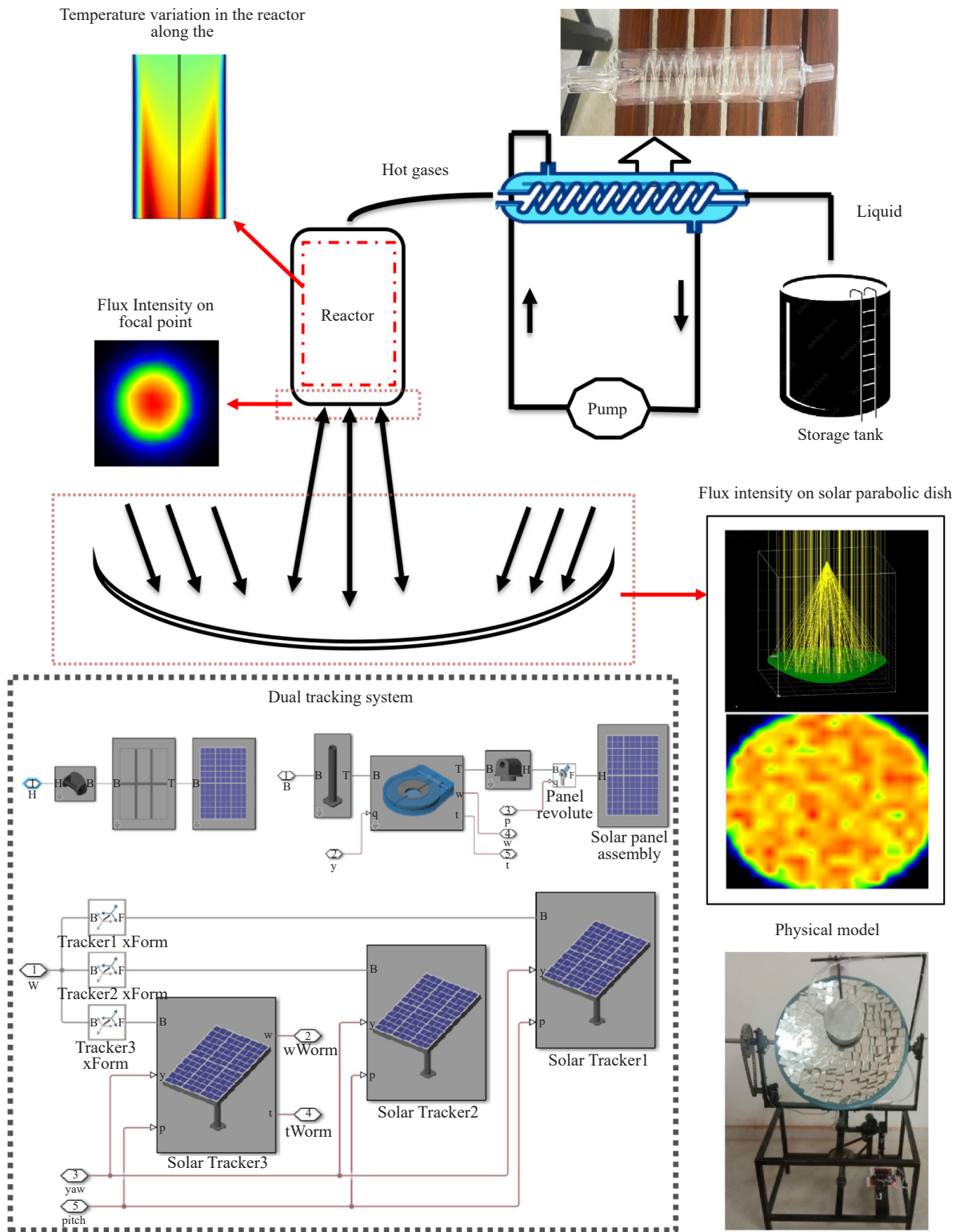


Figure 3. Schematic diagram

Although traditional solar concentrators employing glass or metal mirrors have been thoroughly analyzed, their expense, weight, and complexity restrict them from being used on a large scale. This has established a substantial research deficit with respect to analyzing the performance potential of low-cost, light-weight substitutes such as emergency blankets. Also, effective design parameters that integrate optical functionality with other requirements are a crucial need. In an effort to fill this research deficit, this study aims to experimentally analyze new reflective material configurations for light-weight parabolic dish concentrators. Since the effectiveness of this scheme is purely dependent on maximizing solar radiation collection, a dual-axis solar tracking device has been designed to provide more effective results compared to single-axis solar tracking systems. A graphical representation of the scheme, consisting of the concentrator, solar reactor, and solar tracking device, is given in Figure 3.

3. Mathematical modelling

This section aims to analyze the heat radiation coming from the sun and how it's observed from Earth to get a grip on the physics of solar radiation for the examination of solar energy systems.

3.1 Heat and radiation from the sun

Energy is continuously generated through nuclear fusion reactions occurring in its core, releasing approximately 3.8×10^{23} kW of energy in the form of electromagnetic radiation. Earth, located at an average distance of about 150 million kilometers from the sun, intercepts only a very small fraction of this energy, estimated to be around 1.7×10^{14} kW. Solar radiation refers to the electromagnetic energy emitted by the sun and received by the Earth. Due to atmospheric absorption and scattering, the solar irradiance reaching the Earth's surface is significantly reduced. Under Standard Test Conditions (STC), the reference solar irradiance is assumed to be approximately $1,000 \text{ W/m}^2$ at an ambient temperature of $25 \text{ }^\circ\text{C}$ and an Air Mass (AM) of AM 1.5, which is commonly adopted for solar energy modeling and performance evaluation.

Irradiance, or q_s , is the standard measure of the amount of solar energy received per unit area. It changes depending on the collector's orientation, location on Earth, weather, and time of day. In concentrating systems, the proportionality of the solar energy concentrated on the reflector, q_s (W/m^2), and the collector area, A_a , determine the net solar energy, Q_s . The ratio of the useful energy delivered to the energy incident on the collector aperture is known as the thermal efficiency. As a result, the radiation that reaches the receiver q_0 depends on the optical efficiency, which takes into consideration all errors.

3.2 Sun position

It is important for parabolic dish concentrator systems to compute with the sun's position mathematically since the Earth revolves around the sun and its polar axis every day. Azimuth and elevation angle are two variables that can be used to define the coordinates of the sun's position at any given time, as seen in Figure 4. Equations (1) and (2) demonstrate that both angles are functions of time and site location, respectively.

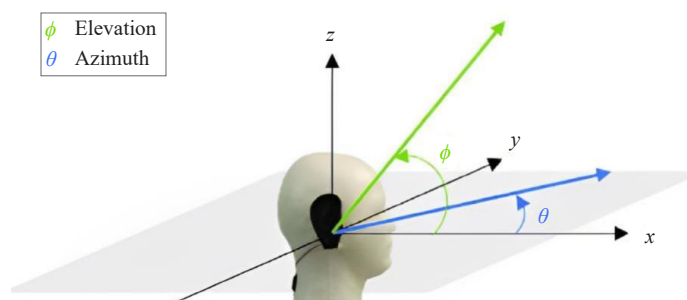


Figure 4. Azimuth and elevator angle

$$\theta = \cos^{-1} \frac{\sin(\delta) \cos(\phi) - \cos(\delta) \sin(\varphi) \cos(\omega)}{\cos(\phi)} \quad (1)$$

$$\phi = \sin^{-1}(\sin \delta \sin \varphi + \cos \delta \cos \varphi \cos \omega) \quad (2)$$

3.3 Collector

As shown in Figure 1, solar collectors are divided into distinct tracking structure designs and operating principles. The Parabolic Dish Concentrator (PDC) is a single focus type and therefore specifies the highest temperature compared to other collector structures. PDC and thermal analysis details are covered in the next two sections.

3.4 Parabolic dish

The geometry of the parabolic concentrator is defined in the x - y coordinate system which is illustrated in Figure 5. Its profile is governed by equation (3), while the corresponding focal point is specified by equation (4).

$$y = x^2/4f \quad (3)$$

$$f = D^2/16d \quad (4)$$

where f is the dish focal point, D is the dish diameter, and d is the dish depth as detailed in Table 1. The rim angle ϕ_r is the angle between the sun's rays and the line from the focal point to the rim of the concentrator shell. The angle of the edge affects the solar radiation beam and the production of a parabolic dish. The parabolic rim angle is given in equation (5).

$$\phi_r = \tan^{-1} \left(\frac{D/2}{f-d} \right) = \tan^{-1} \left(\frac{4fD/2}{4f^2 - (D/2)^2} \right) \quad (5)$$

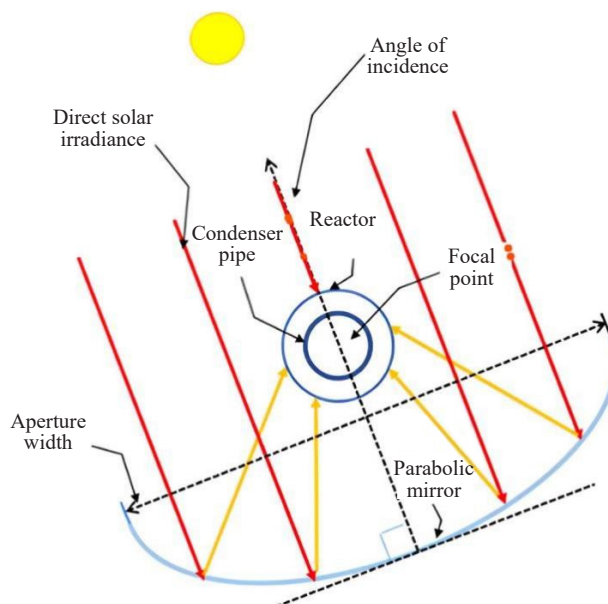


Figure 5. Graphical representation of the parabolic curve

The concentration ratio (C) is a critical parameter that determines the efficiency of solar panels. It is defined as the ratio of the aperture area to the receiver area, as mentioned in equation (6). For effective performance, the solar radiations needs to be concentrated on solar panels. It is estimated that the flux density of solar radiation is less than $1,000 \text{ W/m}^2$.

$$C = \frac{A_a}{A_r} \quad (6)$$

Table 1. Design parameters of a parabolic dish

Specification	Value
Diameter	0.61 m
Concentration ratio	100
Focal point	0.06 m
Rim angle	45°
Aperture area	0.785 m ²
Depth	0.01 m
Receiver area	0.00583 m ²

3.5 Thermal analysis

As shown in equations (7) and (8), the radiation intensity (q_s) of light that strikes the dish multiplied by the aperture area (A_a) yields the amount of heat extracted from the dish. The heat loss (Q_{loss}) from the receiver to the surrounding temperature is used to evaluate the concentrator efficiency as mentioned in equations (9) and (10).

$$Q_s = q_s A_a \quad (7)$$

$$q_0 = \eta_0 q_s = \frac{\eta_0 q_s}{A_a} \quad (8)$$

$$Q_{\text{loss}} = Q_s - Q \quad (9)$$

$$Q_{\text{loss}} = U_r A_r (T_r - T_0) \quad (10)$$

where U_r is the overall heat transfer coefficient and A_r is the receiver area. Equation (10) indicates that the temperature reaches its maximum at the receiver if all heat loss is to the environment. This temperature can be expressed in dimensionless form as equation (11).

$$\theta_{\text{max}} = \frac{T_{r, \text{max}}}{T_0} = 1 + \frac{Q_s}{U_r A_r T_0} = 1 + \frac{q_s A_a}{\eta_0 U_r A_r T_0} = 1 + \frac{q_s C}{\eta_0 U_r T_0} \quad (11)$$

3.6 Collector efficiency

$$\eta_c = \frac{Q}{Q_s} = 1 + \frac{\theta - 1}{\theta_{\max} - 1} \quad (12)$$

In this study, the collection efficiency of oil waste is measured by Conversion Efficiency (CE) (wt%), Waste Reduction Efficiency (WRE) (wt%), and Oil Recovery (OR) (ml oil/kg plastic), expressed by the equation (13), (14), and (15), respectively.

$$CE = \frac{w_o}{w_{sm}} \times 100\% \quad (13)$$

$$WRE = \frac{w_{sm} - w_c}{w_{sm}} \times 100\% \quad (14)$$

$$OR = \frac{V}{w_{sm}} \quad (15)$$

4. Design and optimization

The design details for parabolic solar dishes are given in this section. Table 1 lists the solar dish collector's dimensions, which include a diameter of one meter and a rim angle of 45°. The emergency blanket's dimensions of 1.2 m by 2.4 m limited its circumference to 0.61 m.

4.1 Reflector

To effectively reflect a solar beam into the receiver, the reflector material needs to be highly reflective. But the material needs to be readily available, reasonably priced, and of excellent quality. Three reflector materials, including PET mirrors, emergency blankets, and mirrors, were examined in the current study.

4.2 Tracking structure

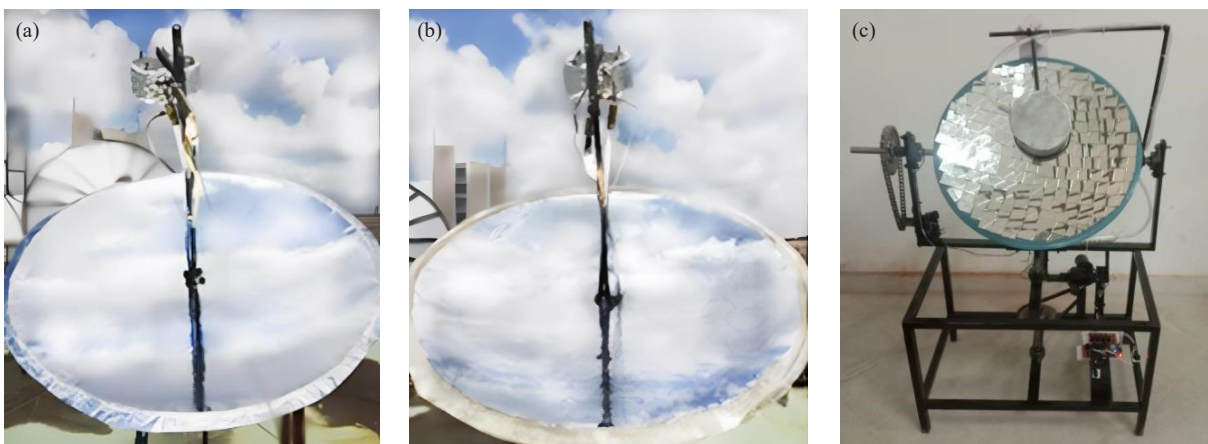


Figure 6. Three distinct reflector dishes: (a) emergency blanket; (b) PET mirror; and (c) mirror

A point-focus optical system is the parabolic concentrator. For maximum efficiency, a dual-axis solar tracking system is consequently required. To maintain the identical circumstances in this study, three dishes with a diameter of one meter must be examined concurrently. As a result, a two-axis sun tracking system was produced, as seen in Figure 6. The building is designed to be lightweight and portable. As a result, the azimuth and elevation angles are decoupled, allowing for independent control and optimization of each axis to maximize solar radiation capture. Figures 6 and 7 show the different reflector dish configurations and the physical model of the dual-axis tracking system, respectively. The focal point temperature measurements under tracking and non-tracking conditions are discussed separately in the results section.



Figure 7. Physical model of dual tracking system

5. Results and discussion

Solar parabolic dish concentrators with a rim angle of 45° and a diameter of 0.61 m were investigated to evaluate the influence of reflector material and tracking configuration on thermal performance. Three reflector materials—PET mirror, emergency blanket, and conventional mirror—were fabricated and tested under comparable conditions using identical dish geometry. Figures 6 and 7 illustrate the reflector dish configurations and the physical implementation of the tracking system. The focal point temperature measurements obtained under tracking and non-tracking conditions are discussed in the Results section. Figures 8 and 9 present a comparative analysis of power output for static, single-axis tracking, and dual-axis tracking configurations at different time periods.

The simulations shown in Figures 8 and 9 were performed to quantify the power output enhancement achieved through solar tracking under identical solar radiation conditions. Hourly solar position parameters, including solar altitude and azimuth angles, were calculated for the selected location under representative clear-sky conditions. In the fixed-mount configuration, the reflector orientation remained constant throughout the day, whereas the single-axis tracking system followed the apparent daily motion of the sun along one axis. The dual-axis tracking system continuously adjusted both azimuth and elevation angles to maintain near-normal incidence of solar radiation on the reflector surface. At each hourly time step, the incident solar power was determined based on the effective projected aperture area, and the useful power output was estimated by accounting for optical efficiency losses, including reflector reflectivity and geometrical concentration effects. Identical reflector area and optical properties were assumed for all configurations to ensure a fair comparison, and the resulting hourly power outputs were used to generate Figures 8 and 9.

The output parameters of three different dishes are displayed in Table 2. The three plates' data and experimental outcomes were displayed. Other intriguing ratios include the mass and cost of each per its heat power, in addition to the maximum temperature and heat power. According to the results, dish 1 with an emergency blanket had the lowest cost per heat power (1.41 THB/W) and mass per heat power (1.04×10^{-3} k/W).

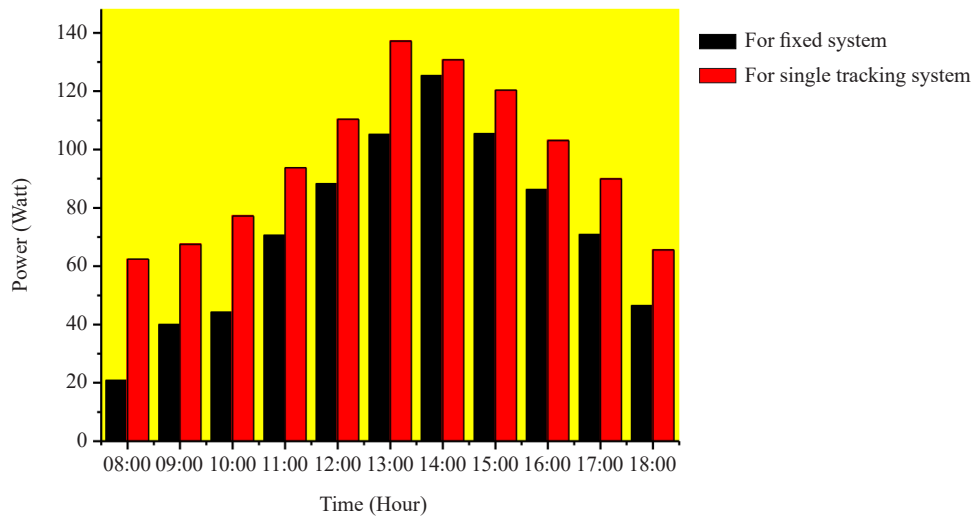


Figure 8. Static versus single-axis simulation result for comparison of fixed mount and single-axis tracker system

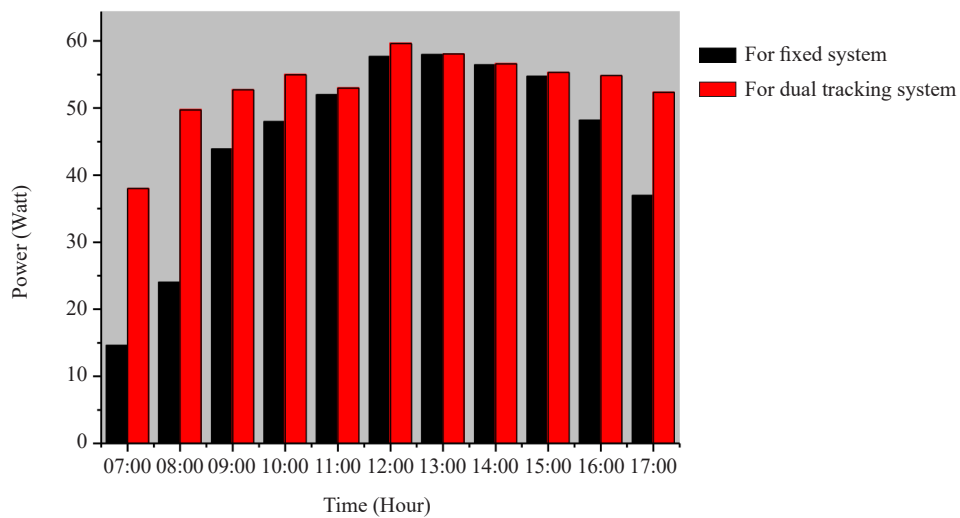


Figure 9. Fixed versus dual-axis simulation result for comparison of fixed mount and dual-axis tracker system

Table 2. Different outputs of different dishes

Data	Dish 1	Dish 2	Dish 3
Diameter (m)	1	1	0.61
Cost per heat power (TBH/W)	1.41	3.46	3.34
Maximum focal point temperature (°C)	817	724	807
Reflector material	Emergency blanket	PET-mirror	Mirror
Maximum heat power (W)	389	361	380
Mass (Kg)	4.04	4.84	4.91
Mass per heat power ($\times 10^{-3}$ kW)	1.04	1.34	1.33
Cost (TBH)	550	1,250	1,735

6. Conclusions

The current study describes the process of fabricating parabolic dishes. Using an emergency blanket mold to form a resin parabolic dish is a versatile method. With this method, inexpensive dishes with a range of rim angles and sizes can be produced. For research purposes, it is therefore perfect to design a parabolic dish. Through experimental testing, the performance of three solar parabolic dishes: a mirror, a PET mirror, and an emergency blanket with varying reflector materials was examined. The dish's dimensions are 1 m in diameter, 0.61 m in focal length, and 45° in rim angle. The tested dish was rotated toward the sun using the dual-axis tracking technology to maximize the effectiveness of the solar dish. According to the trial results, the dish with an emergency blanket, Mirror, and PET-Mirror may reach maximum temperatures of 817 °C, 874 °C, and 724 °C, respectively. The dish with emergency blanket, mirror, and PET-mirror has respective heat powers of 389 W, 361 W, and 420 W. The mass of each dish in relation to its heat power and the fabrication cost in relation to its heat power were additional criteria that were included. The dish with the emergency blanket had the lowest mass per heat power (1.04×10^{-3} k/W) and cost per heat power (1.41 THB/W), according to the results. This demonstrates that the cost and efficiency of the fabrication method make it worthwhile.

7. Future recommendations

The current study proposes the following recommendations for further research:

- Apply catalysts in fuel synthesis from plastic waste pyrolysis to reduce the temperature needed to break hydrocarbon bonds, enhancing yield and efficiency.
- Improve isolation and segregation of plastic waste before pyrolysis to ensure consistent material properties and better thermal decomposition.
- Develop contamination-free pre-treatment of plastics to prevent impurities from affecting pyrolysis product quality.
- Optimize physical pre-treatment (shredding, cutting) to increase heat transfer and accelerate thermal decomposition.
- Implement comprehensive health and safety measures during the fabrication and handling of pyrolysis products for safe industrial application.

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Conflict of interest

The authors declare that they have no competing interests.

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