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Converting Plastic Waste into Electricity Using Solar Gasification Technique

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Abstract—**Plastic waste is a global environmental problem that needs better management and use. Based on the 2030 vision, Bahrain aims to reduce the percentage of carbon dioxide emissions. Unfortunately, the current methods of dealing with plastic waste, such as landfills and incineration, do not serve this goal; on the contrary, they increase environmental damage. Solar gasification is an innovative and long-term solution to these long-standing issues.**

In this work, we investigated a solution to the plastic waste problem by using a solar gasification plastic waste-to-energy converter, a new idea in the Bahrain market. Solar gasification is an innovative and environmentally friendly method for managing plastic waste. The solar dish-type thermal collector is modeled to produce thermal energy at a very high temperature, which energizes a decomposition process to produce gas, leading to power production in a gas power cycle. The gasification and gas power cycle was simulated in Aspen Plus to estimate the power produced.

Keywords—solar dish, gasification, Aspen plus, waste plastics .

I. INTRODUCTION

Growing populations cause more plastic waste, a significant problem in every country worldwide. Polyethylene, followed by polypropylene (18.9%) and polyethylene (29.6%), is the most common plastic manufactured globally [1]. Both landfilling and incineration are viable methods for handling plastic trash. Carbon dioxide emissions are a drawback of both landfilling and incinerating waste.

Despite being recyclable and reusable, plastic waste eventually becomes trash or is no longer recyclable. Much emphasis has been placed on turning plastic trash into other goods to increase its value [2–5].

Currently, gasification and pyrolysis are two methods for turning plastic trash into an energy carrier. Oil fuel can be supplied when plastic waste is heated to 300 and 650 ◦C without oxygen during pyrolysis. Syngas or synthesis gas can be produced during the gasification process when plastic waste reacts with gasifying agents (such as steam, oxygen, and air) at a high temperature of 500–1300 ◦C. To obtain the necessary temperature of 800 ◦C in an environmentally friendly way, renewable energy such as the sun, fixed mirrors, and focus points reflect the sun's rays to the receiver and transfer them to the gasifier unit. The final output is the primary distinction between both approaches. This study has concentrated on the gasification of plastic trash since syngas could create various products and fuel for fuel cell machines to generate power.

The Aspen Plus simulator is a valuable tool for theoretical calculations, even though little practical research is focused on the gasification of plastic waste. The results can be used as guidelines for actual operations. This method can be used in a large-scale application by simulating the entire process.

II. BACKGROUND AND LITERATURE REVIEW

A. *Background*

Dumping and landfilling waste plastics have been used as conventional waste disposal methods for decades, but serious environmental and economic concerns plague them. Plastics have degraded over centuries, emitting hazardous chemicals to the Earth's soil and water, leading to environmental pollution. Furthermore, landfills require large land areas, leading to urban land scarcity. The release of methane, a potent greenhouse gas, from buried plastics causes climate change concerns. Transporting waste to these locations for disposal consumes energy and produces further emissions, whereas essential petrochemical resources contained in plastics are wasted.

B. *Literature Review*

The analyzed literature describes the role of hybrid energy systems, renewable energy, and modern methods of power generation, which are more critical in the present world. According to Berrada et al., hybrid energy systems utilize solar, wind, and fossil energy to achieve system reliability and low Green House Gas emissions. However, such systems are characterized by high costs and use of renewable energy sources that are sporadically available. Stress on using energy storage systems is a significant parameter, essential for matching power supply and energy demand.

Solar parabolic dish systems and related technologies in renewable energy are also investigated based on their ability to perform highly and be eco-friendly. Hafez et al. (2016) explain how they operate by concentrating sunlight to produce power and hence can work independently of the grid.

They have suboptimal thermal characteristics, and thermal modeling methods improve their performance and arrangement. As Khaligh (2018) asserted, solar and wind energy can help reduce global climate change. The ignorance of wind and solar energy is detrimental to human civilization. Khaligh also underlined that there is virtue in hybridism, which endears fairness and stability to a society's management of energy sources.

Other such opportunities include using a technique such as gasifying plastic waste. Saebea et al. (2020) focus on converting plastic waste into syngas, a composition of hydrogen and carbon monoxide prepared using both temperature and pressure. This method shows that it could be practical to solve two major issues: waste management and energy at agreeably low pollutive output.

Electric generators, especially synchronous generators, are another area of concern in the literature. We learn more about them, their construction, operating principles, and their usefulness, with special reference to their use in renewable energy systems from Henry and Henry (2023). These machines optimally work to transform mechanical energy into electrical energy to support stable power production. Fahad (2021) accounts for its uses in personal power systems. Admin (2023) will give general information on the types and parts of batteries that make them usable in any field. Together, the literature captures a need to consider using advanced technologies and renewable solutions to tackle energy and environmental issues.

III. METHODOLOGY

A. *Process description*

Fig. 1 shows the schematic of the gasification of plastic waste designed in the Aspen Plus simulator. The plastic wastes considered in this work consist of polyethylene. In actual practice, plastic waste can be directly supplied to the gasifier, which reacts with steam as a gasifying agent. Since plastic waste is a non-conventional component, it must be decomposed into each element before the reaction occurs.

The simulation represents an integrated energy cycle that starts with the conversion of a feedstock in the DECOMP to produce heat, then gasifies it in the GASIFIER to produce hot gas that is combined with compressed air in the combustion chamber (COMB) to generate high-pressure gas. The turbine uses this gas to create mechanical power (274 kW). At the same time, the waste heat is recovered in the heat recovery system (HRSG) to heat water and produce steam, with solid waste separated during the process. The system efficiently uses energy to generate mechanical power while minimizing heat losses.

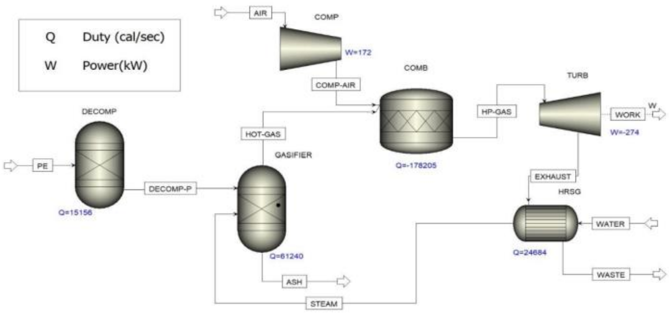


Fig. 1. Gasification of plastic waste.

This study represents the breakdown of plastic waste as an unconventional component into an element using the RYield reactor model. The R Gibbs reactor model is used to represent gasifiers because of the wide range of reactions that can take place there. Listed below are the chemical processes that might take place during steam gasification:

- Boudouard Reaction:
$$C + CO_2 \leftrightarrow 2CO \qquad \Delta H = +172\ \frac{KJ}{mol} \tag{3}$$
- Water-Gas Reaction:
$$C + H_2O \leftrightarrow CO + H_2 \qquad \Delta H = +131\ \frac{KJ}{mol} \tag{4}$$
- Hydrogasification:
$$C + 2H_2 \leftrightarrow CH_4 \qquad \Delta H = -74.8\ \frac{KJ}{mol} \tag{5}$$
- Water-Gas Shift Reaction:
$$CO + H_2O \leftrightarrow CO_2 + H_2 \qquad \Delta H = -41.2\ \frac{KJ}{mol} \tag{6}$$
- Metalation Reaction:
$$CO + 3H_2 \leftrightarrow CH_4 + H_2O \qquad \Delta H = -206\ \frac{KJ}{mol} \tag{7}$$
- Reforming Reaction:
$$CH_4 + H_2O \leftrightarrow CO + 3H_2 \qquad \Delta H = +206\ \frac{KJ}{mol} \tag{8}$$

B. *Modeling and Simulation*

The solar dish provides heat to the gasifier to start the process, as illustrated in Fig.2.

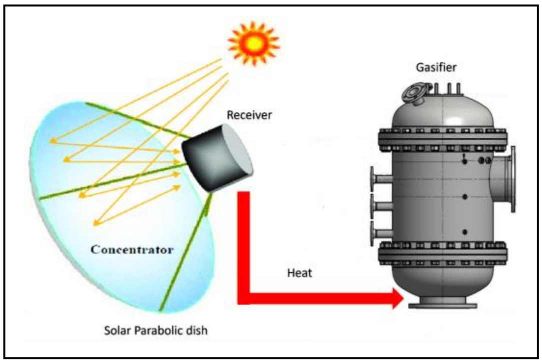


Figure 2: Schematic of the solar dish and gasifier [Kongtragool and Wongwises 2003]

The overall design scheme of the solar dish is shown in Fig. 3:

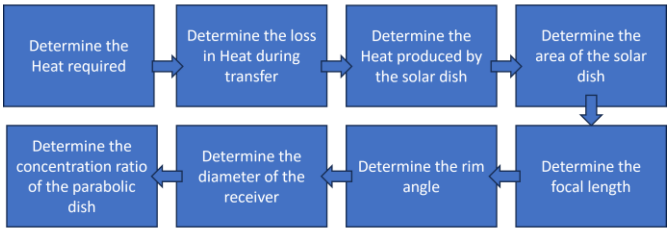


Fig. 3. Design Steps for Solar Parabolic Dish Systems.

- Aspen Plus Simulation:

Aspen Plus is a versatile process simulation tool renowned for its capability to model and optimize various chemical processes. Engineers and researchers leverage its comprehensive platform to effectively design and analyze complex systems. In our gasification simulation, we opted for the widely used Peng Robinson fluid package within Aspen Plus, known for its accuracy in predicting thermodynamic properties crucial for gasification studies.

- Decomposition of Plastic:

In simulating polyethylene within Aspen Plus, "decomposition" refers to breaking down complex polyethylene molecules into their chemical constituents. Polyethylene is a polymer composed of repeating units of ethylene, and during the decomposition process, these polymer chains are essentially "unzipped" or separated. This step is crucial because Aspen Plus relies on accurate information about the chemical composition and properties of the substances involved in a simulation.

- Design of Solar Dish

The total amount of heat required for 100 kg of plastic.

$$Q = m * c_p * \Delta T$$

where Q is the heat in J, m is the mass of plastic in kg, and c_p is the specific heat of plastic in J/kg. K and ΔT are the temperature changes.

Assuming a 10 % thermal loss, the total thermal power of the solar dish is:

$$Q_s = Q + Q_{loss}$$

In order to calculate the solar dish's power output, we need to consider the available time, which we assume is 1h (3600s). We need to consider the solar irradiation in Bahrain to calculate the area of the solar dish that provides the required heat.

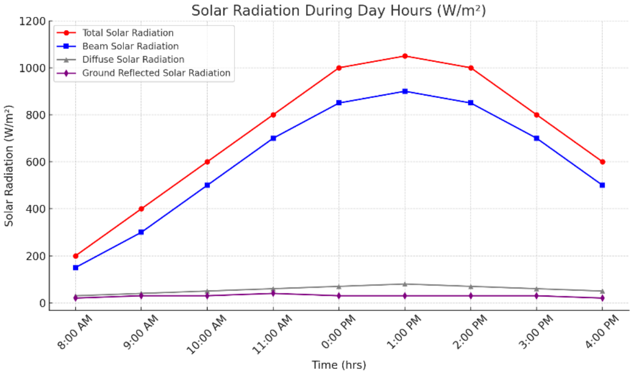


Fig. 4. Solar Radiation Throughout the Day

Fig. 4 shows the variation of solar radiation on Bahrain's typical summer day in terms of global, beam, diffuse, and ground reflection. The required power (P) and aperture area (A) of the solar dish is given by:

$$P = \frac{Q}{t}$$

$$A = \frac{P}{G}$$

Where G is the global solar irradiation (W/m^2).

The radius of the solar dish (see Fig. 5) is:

$$R = \sqrt{\frac{A}{\pi}}$$

The maximum angle that defines the diameter of the aperture in (degree) is given by:

$$\emptyset_{rim} = \frac{1}{2} tan^{-1}\left(\frac{1}{F}\right) = \frac{1}{2} tan^{-1}\left(\frac{1}{0.25R}\right)$$

Where F is the focal length in meters.

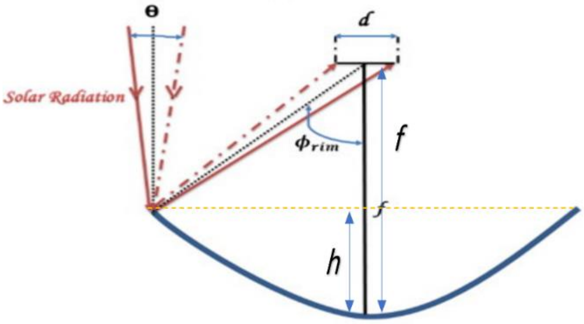


Fig. 5. Schematic of a Solar Parabolic Dish System

The distance from the vertex to the aperture *(h)* and diameter of the receiver (*D*) are given as:

$$h = \frac{4R^2}{16F}$$

$$D_{rec} = \frac{F\theta}{cos(\emptyset_{rim})\,[1 + cos(\emptyset_{rim})]}$$

Where θ is the angle of solar radiation

The concentration ratio (*C*) of the parabolic dish:

$$C = \frac{A}{A_{rec}}$$

Thermal power concentration (Q_{focus}) at the focus is expressed as:

$$Q_{focus} = C \times G = \sigma \times \epsilon \times T^4_{max}$$

where ϵ is the Emissivity for Black-Coated Aluminium, and T_{max} represents the maximum temperature.

IV. RESULTS AND DISCUSSION

The computed values of the solar dish geometrical parameters are illustrated in Table 1.

Table 1. Solar dish specifications

Solar dish Radius	5 m
Focal length	1.25 m
The radius of the receiver	0.151 m
The surface material	Aluminium
Θ_{rim}	19.33 °
Distance from vertex to the aperture	5 m
Concentration ratio	1096

Fig. 6 illustrates the temperature versus concentration ratio curve, showing that a concentration ratio of 1096 would give rise to a temperature of 1760 °C.

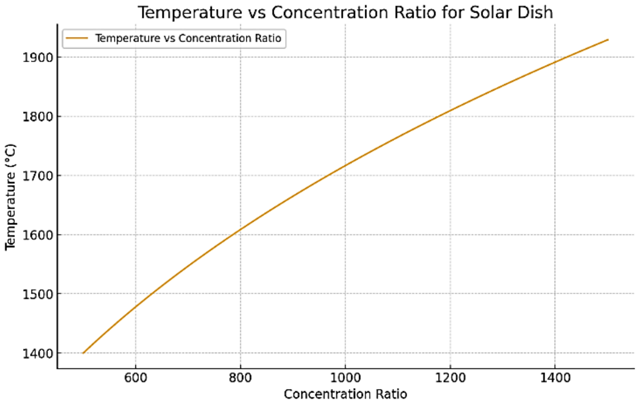


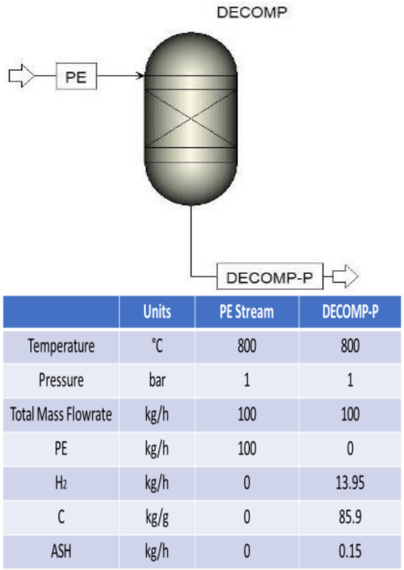
Figure .6. Temperature vs Concentration Ratio for Solar Dish

The efficiency of the decomposition process can be evaluated by looking at the conversion rates and product output. In this case, the process converts 100 kg/h of polyethylene (PE) into 85.95 kg/h of hydrogen gas (H_2) and 0.15 kg/h of ash, as depicted in Fig. 7 from Aspen Plus. This indicates a high conversion efficiency, especially for hydrogen production.

- Hydrogen Yield: The process yields 85.95 kg/h of hydrogen from 100 kg/h of PE, which is approximately 86% efficiency in terms of hydrogen production.

- Ash Production: The minimal ash production (0.15 kg/h) suggests that most of the PE is converted into valuable products, indicating a clean and efficient process.

This high efficiency makes the process promising for generating hydrogen fuel from plastic waste, contributing to sustainable energy solutions.



	Units	PE Stream	DECOMP-P
Temperature	°C	800	800
Pressure	bar	1	1
Total Mass Flowrate	kg/h	100	100
PE	kg/h	100	0
H_2	kg/h	0	13.95
C	kg/g	0	85.9
ASH	kg/h	0	0.15

Figure .7. Decomposition of Plastic in a Reactor

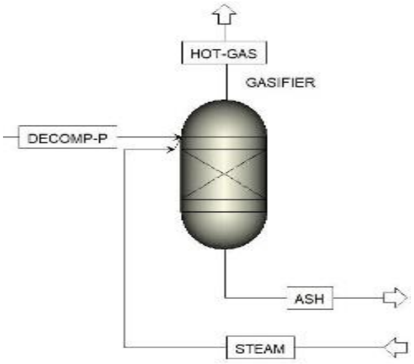
- Gasification Results

  The efficiency of the gasification process can be evaluated by examining the conversion rates and the output of valuable products. Here are some key points:

- *Hydrogen Production:* The process produces 216.5 kg/h of hydrogen from a total mass flow rate of 215.8 kg/h of HOT-GAS. This indicates a high efficiency in terms of hydrogen yield.

- *Carbon Dioxide and Methane:* The process also generates 164.4 kg/h of CO2 and 11.8 kg/h of CH4, which are significant by-products.

- *Residual Heat:* The residual gasification heat in the ash is minimal (0.15 kJ/kg), suggesting efficient energy utilization.

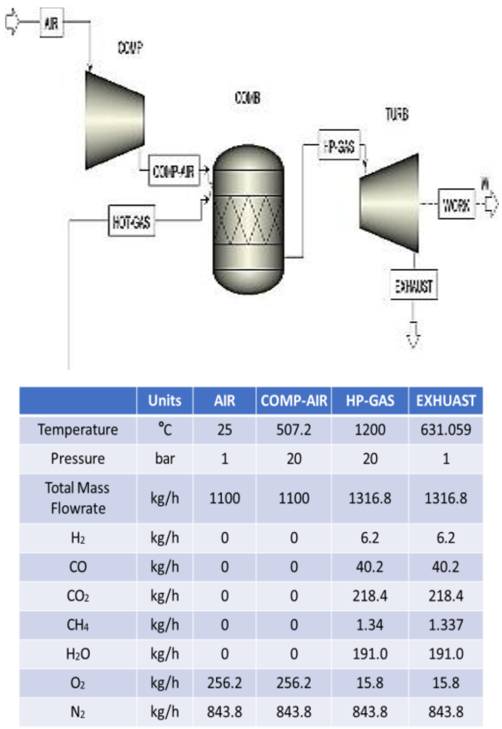


	Units	HOT-GAS	ASH	STEAM
Temperature	°C	800	800	800
Pressure	bar	1	1	1
Total Mass Flowrate	kg/h	216.8	8.20	125
H_2	kg/h	25.5	0	0
CO	kg/h	164.4	0	0
CO_2	kg/h	11.8	0	0
CH_4	kg/h	5.47	0	0
H_2O	kg/h	9.53	0	125
Residual	kg/h	0	8.05	0
ASH	kg/h	0	0.15	0

Figure .8. Gasification Results in a Reactor System

The efficiency of the gas turbine system can be evaluated by examining the conversion of input air into useful energy and the emissions produced (see Fig. 9):

- *Pressure and Temperature:* In the compressor stage, the air is compressed from 1 bar to 20 bar and heated from 25°C to 507.2°C.
- *Total Mass Flowrate:* The mass flow rate remains consistent at 1100 kg/h through the stages and the gas turbine's power output is computed to be 274 kW.



	Units	AIR	COMP-AIR	HP-GAS	EXHAUST
Temperature	°C	25	507.2	1200	631.059
Pressure	bar	1	20	20	1
Total Mass Flowrate	kg/h	1100	1100	1316.8	1316.8
H_2	kg/h	0	0	6.2	6.2
CO	kg/h	0	0	40.2	40.2
CO_2	kg/h	0	0	218.4	218.4
CH_4	kg/h	0	0	1.34	1.337
H_2O	kg/h	0	0	191.0	191.0
O_2	kg/h	256.2	256.2	15.8	15.8
N_2	kg/h	843.8	843.8	843.8	843.8

Fig. 9. Gas Turbine and operational parameters

- *Emissions:* The exhaust contains 316.8 kg/h of CO2, 218.4 kg/h of CO, and 1.94 kg/h of CH_4. These emissions are typical for gas turbines but can be optimized for better efficiency and lower environmental impact.

V. CONCLUSION

In this work, mathematical calculations are performed to estimate the solar dish's potential to generate heat at temperatures above 1000 C to melt the plastic waste (polyethylene) and produce hydrogen gas in a gasification process. The gasification process of powering a gas power plant was modeled in Aspin Plus.

The results demonstrated that a simplified model of the solar dish with a rim angle of 19 degrees and concentration ratio of 1096 resulted in a temperature of over 1700 °C. The decomposition process converted 100 kg/h of polyethylene (PE) into 85.95 kg/h of hydrogen gas (H2) and 0.15 kg/h of ash, ultimately producing 274 kW in the gas power cycle.

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