Plastic Killers

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Introduction:

Since the beginning of the project creation procedures, the EDP (Engineering Design Process) has been followed to justify the challenge's solution as its determining steps were in consideration to get the required results:

- **First:** the challenge has been identified and studied well which is producing energy from one of these points:
    - By-products (excluding animal wastes and farming).
    - Greenhouse gases.
    - Waste heat.

  to get all information that is involved to be capable of choosing the accurate solution to achieve the desired prototype.

- **Second:** the most appropriate and proper solution was selected to solve the semester challenge and this was done through searching for prior solutions, knowing their strength and weakness points, and understanding why some of them haven't been applied so far since the used material or substance can generate energy through some processes.
- **Third:** the design requirement that the solution's hypothesis was set based on it is the path that the team should follow to achieve the best results.
- **Fourth:** the selected solution is determined and applied to prove that it is applicable and satisfies the capstone challenge prerequisites to generate and produce energy at the end.
- **Fifth:** test plan
- **Sixth:** at the end of the project, its results are shared among the others to communicate and get benefit and experience from each capstone group by being curious of what are the obstacles that were exposed to them and how they overcome those opposes.

l. Present and Justify a Problem and Solution Requirements:

Egypt Grand Challenge(s):

Egypt suffers from many problems. These problems are called Egypt's grand challenges. The challenge is to search for solutions to these problems. Waste recycling is the problem that is focused on during the research.

Fig (1) Grand Challenges

Recycle garbage and waste for economic and environmental purposes

The entire world including all countries whether the developing or developed ones suffers from an abundance of waste and garbage which cause high climatic pollution, and heath degradation due to water, air, and soil contamination. For instance, global warming is brought about neglecting the existence of garbage as its percentage increases over time. In addition to synthesizing plastics and materials to use them for various purposes, that increases the percentage of contaminating substances as well. As a result, the governments and authorities think of environmental reclamation through recycling garbage and waste as their configuration conversion and making them enter other industrial processes has availed the environment through protecting it.

Various points emit contaminated fumes or are compartmentalized to be mischievous which are: by-products especially plastics, greenhouse gases, and heat waste, so it is preferable to reuse those points for a beneficial purpose, therefore the scientists and experts try to find a solution to recycle them. (Badr, H. 2017)

There have been some initiatives from the Egyptian government toward improving waste management in the country. In 2013 the Ministry of Environment launched a national campaign, which focused on improving how garbage is collected, transported, and recycled. Another example is Cairo in 2012 where they started a project which involved monitoring waste management by using IT. Initiatives have also been made to include the citizens of Egypt regarding how they consume, reuse recycle, etc. This means increasing awareness in the public through for instance education and media. (Jersey Waste Wise Business Network, 2015).

Fig (2) Plastic Pollution in Egypt

Address and reduce pollution fouling our air, water, and soil

Despite the technological development and continuity, humans haven't paid the catastrophes that occurred due to contamination attention or even made their reckoning busy with them. As passing time, the pollution percent one in the whole planet gets higher, so the medical authorities have decided to address and adjust its percentage to keep the Earth safe. Greenhouse gases, car fumes, and poisonous gases that are released from chemical reactors affect the atmosphere as when they're inhaled, the human animals' lungs will be damaged surely. When they rip, they condense among the air particles creating an acidic rain that carries denigrative nitrogen acids, which pollute the water and soil. Finally, the cycle of iterating those

Fig (3) Single-use plastic pollution

Fig (4) Environmental Protection Agency

juveniles can be controlled through the efforts that geologists make as some prior solutions have been attained to reduce the pollution abundance in the environment. (Food and Agriculture Organization of the United Nations, 2018).

EPA (Environmental Protection Agency in the United States) declared in 2009 that greenhouse gases (carbon dioxide, methane, fluorinated gases, and, nitrogen oxides) that are emitted endanger human health and surely are characterized to perish green regions. In May 2010, the National Research Council, the operating arm of the National Academy of Sciences, published an assessment which cot hated that "climate change is occurring, is caused largely by human activities and poses significant risks for - and in many cases is already affecting - a broad range of human and natural systems.".

The NRC (National Register of Citizens) has advertised and approved that the brief is based on findings that are consistent with several other major assessments of the state of scientific knowledge on climate change.

(Food and Agriculture Organization of the United Nations, 2018)

Fig (5) National Register of Citizens

Reduce and Adapt to the effect of climate change

The effects of human-caused global warming are happening now, are irreversible on the timescale of people alive today, and will worsen in the decades to come. Global climate change has already had observable effects on the environment. Glaciers have shrunk, ice on rivers and lakes is breaking up earlier, plant and animal ranges have shifted, and trees are flowering sooner.

Effects that scientists had predicted in the past would result from global climate change are occurring now like loss of sea ice, accelerated sea-level rise, and higher, more intense heat waves.

Scientists are pretty sure that global temperatures will continue rising for decades to come, largely due to greenhouse gases produced by human activities. The Intergovernmental Panel on Climate Change (IPCC), which includes more than 1,300 scientists from the United States and other countries, forecasts a temperature rise of 2.5 to 10 degrees Fahrenheit over the next century. (My Climate, 2021)

According to the IPCC, the extent of climate change effects on individual regions will vary over time and with the ability of different societal and environmental systems to mitigate or adapt to change.

(United Nations, n.d).

Fig (6) Ice melting at the 2 poles

Problem to be solved:

The problems that Egypt has been encountering are:

1. Recycle garbage and waste for economic and environmental purposes.
2. Reduce and Adapt to the effect of climate change.

The presence of numerous denigrative fumes, harmful gases, garbage, and waste is a big problem Egypt faces as there are limited methods to get rid of those things so far, so the challenge is to innovate or search for a scientifically based information that can be relied on during the project as the challenge is generating and producing energy by using one of the following choices: greenhouse gases, by-products or heat waste.

<u>Recycle garbage and waste for economic and environmental purposes</u>

If the problem (1) is solved:

- Air pollution will be reduced and also the death resulting from it.
- Water pollution problem will be met by recycling garbage and waste.
- The danger that is exposed to humans, animals, and plants will be limited.
- Economic and environmental protection will be achieved from pollution.

If the problem (1) is not solved:

- The problem of air pollution will increase and therefore people are at risk.
- The pollution of the sea and oceans will increase and that makes human and animal life and plant in greater danger, affecting agriculture, industry, and tourism.
- The economy of Egypt will be at risk, and the environment will become an epidemic place where living organisms can't live in.

<u>Reduce and Adapt to the effect of climate change</u>

If the problem (2) is solved:

- Causes of global warming will be reduced, thus reducing its negative effects on living organisms and the environment (ocean acidification for example).

- The problems of (loss of sea ice, accelerated sea-level rise, and longer, more intense heat waves) will be reduced.
- Achieving the possibility of benefiting from greenhouse gases or heat waste in producing energy raising Egyptian and global economy.

If the problem (2) is not solved:

- Increase the ozone hole, so the life of living organisms becomes at risk.
- The water level will be higher and the life of marine organisms becomes in danger and thus threatening tourism and economics.
- Sea and Ocean water will be evaporated and thus decreasing water levels and that means a lack of irrigation water and drinking water.

Research:

Topics that are searched for:

- Which Egyptian Grand Challenge(s) are we addressing, and why are they important to address?
- Positive and negative consequences for each challenge.
- What are the greenhouse gases, waste heat, and by-products from industrial processes (excluding farming and animal wastes), and how can we benefit from each one to produce energy?
- The most by-products are located in Egypt.
- Converting plastic into fuel.
- The most suitable type of plastic for producing a great amount of fuel.
- The optimal kind of catalyst for high temperature and pressure.
- The suitable materials for pyrolysis (converting plastic into fuel) and the cost of each one.
- What are the pros and cons of aluminum? And what are the consequences of using it as a construction material for tubes that are exposed to high-temperature degrees?

ll. Generating and Defending a Solution:

Other Solutions Already tried:

Rocket fuel from CO_2:

This process is accomplished through various steps and methods which are:

- On-demanded CO_2 to alcohol: by using liquid CO_2, water, electricity, and adding Nafion for generating alcohol.
- CO_2 to alcohol with in-situ power generation: using CO_2 power production through CO_2 turbine generation of static electricity generator (SEG) to power the conversion through Nafion.
- Spin to liquid (STL): alcohol production is done via using liquid CO_2 using a cavitation device with Nafion.

Electricity is generated in-situ. The device is required to be resolved by using electricity being generated by (an electric motor and pressure expanding turbines). (Boiron, A. J., Cantwell, B. J. 2013).

Advantages

- Liquid rocket fuel is specialized with higher production of specific impulse (momentum) up to 4500 N s Kg-1, while the solid rocket fuel produces about 2500 N s kg-1, so as the impulsion rate increases, as the efficiency of the machine gets higher, so it consumes short period.

Disadvantages

- As the volume of the rocket fuel is incredibly massive, it requires more pumps and piping to pump the liquid up to be consumed as well as the feeling of a dearth of more capacity or empty area for storing the liquid in.

Thermoelectric generator: it is a generator that is developed by Evonik to convert waste heat that is produced from heat-generating sources such as vehicles engines and motors to electricity. (Mahmud, K. H., Yudistirani, S. A. & Ramadhan, A. I. 2017).

Advantages of TEG:

- Thermoelectric generator is discriminated with its affordability as it requires a low cost to be bought or even manufactured.
- It is capable of converting the heat waste that is emitted from vehicles, engines, or factories for instance: car and factory fumes into a clear renewed energy that is produced in the form of electric energy.
- The environment is protected and shielded because TEG reduces the contaminated air and remaindered waste and works on changing those negative influences into beneficial energy that can increase the income of the country.

Disadvantages of TEG:

- it is less efficient than other sources of energy as it conducts the thermal energy through electrically conducting materials and this is completely the opposite as the required is high electrical conductivity and poor thermal conductivity to ensure that heat gets the electrons moving.
- Lack of industry education of thermoelectric generators, as there is impotency in the numbers of the admitted technicians due to spreading of unemployment with unexpected ratios.

Geothermal energy:

To get benefits from wasted heat, geothermal energy is used as heat (thermal) derived from the earth (geo). The thermal energy contained in the rock and fluid fills the fractures and pores within the rock of the earth's crust. Geothermal resources are reservoirs of hot water that exist at different temperatures and depths below the Earth's surface (source).

Advantages

- Renewable energy

Geothermal energy is a source of renewable energy that will last until the Earth is destroyed by the sun in around 5 billion years. The hot reservoirs within the Earth are naturally replenished, making it both renewable and sustainable

- Heating and Cooling

  geothermal electricity generation requires water temperatures of over 150°C to drive turbines. Alternatively, the temperature difference between the surface and a ground source can be used. Due to the ground being more resistant to seasonal heat changes than the air, it can act as a heat sink/ source with a geothermal heat pump just two meters below the surface.

Disadvantages

- Environmental Side Effects

Although geothermal energy does not typically release greenhouse gases, many of these gases are stored under the Earth's surface and are released into the atmosphere during digging. While these gases are also released into the atmosphere naturally, the rate increases near geothermal plants. However, these gas emissions are still far lower than those associated with fossil fuels.

- High Costs

On large scale, geothermal energy is an expensive resource to tap into, with price tags ranging from around \$2-\$7 million for a plant with a 1-megawatt capacity.

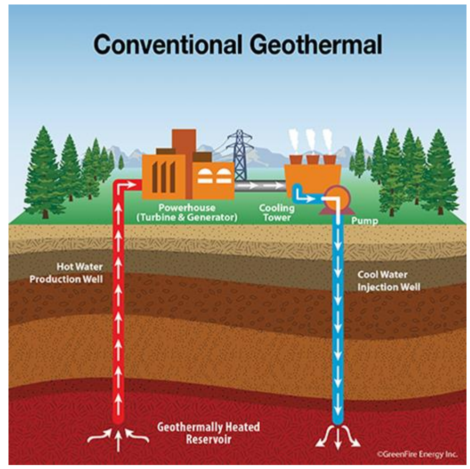


Fig (7) Conventional Geothermal

<u>**Hybrid Na-CO2 System:**</u>

A Hybrid Na-CO2 System is a big liquid battery that gets benefits from wasted co2 by factories. A sodium metal anode is placed in an organic electrolyte, while the cathode is contained in an aqueous solution. The two liquids are separated by a sodium Super Ionic Conductor (NASICON) membrane to allow sodium flow. When CO2 is injected into the aqueous electrolyte, it reacts with the cathode, turning the solution more acidic, generating electricity, and creating hydrogen.

(Kim, C., Kim, J., Joo, S. & Bu, Y. 2018).

Chemical equations involved

(Equation 1) CO_2 (aq) + H_2O(l) ⇌ H_2CO_3(aq), (Equation 2) $H_2CO_3(aq) \rightleftharpoons HCO_3^-(aq) + H^+(aq)$

- <u>Advantages</u>

It has multiple advantages like high electronic conductivity, abundance, tunable pore structure, rich surface chemistry, carbon-based materials that have been extensively applied as active materials, or supports in various energy conversion and storage devices.

- <u>Disadvantages</u>

The inherent disadvantages of large overpotential (resulting in low energy efficiency), limited cycling life, poor rate capability, and serious side reactions hamper their practical applications. These challenges call for high-performance cathodes with effective catalysts, anode with a stable solid–electrolyte interface as well as an advanced electrolyte, which makes it impractical on large scale

Fig (8) Hybrid Na-CO_2 System

COVID-19 masks waste to energy via a thermochemical pathway:

Co-pyrolysis of single-use face masks (for the protection against COVID-19) and food waste was investigated. To this end, a disposable face was pyrolyzed to produce fuel-range chemicals. The pyrolytic gas evolved from the pyrolysis of the single-use face mask and consisted primarily of non-condensable permanent hydrocarbons such as CH_4, C_2H_4, C_2H_6, C_3H_6, and C_3H_8.

- Advantages

That technique provides fewer greenhouse gas emissions as the pyrolysis process is not subjected to oxygen. Also, reduces the total pollution resulting from single-use face masks.

- Disadvantages

The face masks need to be treated before adding the to the process and that might cost a lot of money on a large scale

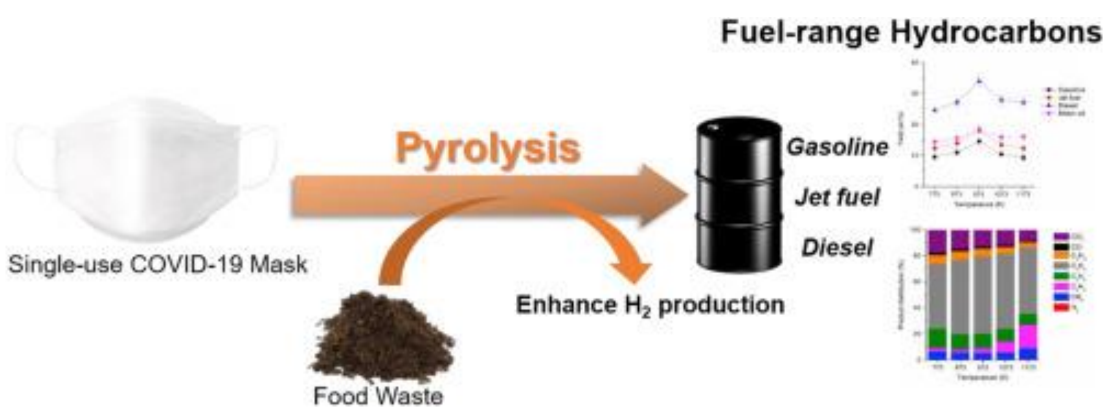


Fig (9) Pyrolysis of Single-use COVID-19 Masks

Solution and Design Requirements:

<u>Problem and solution:</u>

Plastics are inexpensive and durable. As a result, levels of plastic production by humans are high however the chemical structure of most plastics renders them resistant to many natural processes of degradation and as a result, they are slow to degrade. Together, these two factors have led to a high prominence of plastic pollution in the environment. Millions of animals are killed by plastic every year, but they are many ways we can reduce plastic pollution by converting waste plastic into energy resources (fuel).

Chemical recycling is an effective way to reduce the explosive growth of plastic waste and disposal problems. Plastic is just crude oil that has been proved in different ways and by using pyrolysis, this process can be reversed.

Plastic Pyrolysis is a very effective process where plastic is exposed to high temperatures to break down into hydrocarbons that can be used in our daily life.

Plastic is hard to break down and besides the temperature needed for the reaction to occur, there must be a catalyst which is zeolite

Fig (10) HDPE plastic bottles

(Nugroho, A. S., Rahmad, Chamim, M., et al. 2018).

Design Requirements:

The selected design requirement is:

- Time: It can't exceed 20 minutes due to the prior research papers on HDPE pyrolysis under a temperature of 800-1000ºC.

- That can be met by making the dimensions of the output paths short, their arrival to the beakers is easy and in a short time, and

By providing high temperature to increase pressure and thus we get fast response and access.

- That also can be met by choosing materials that bear high temperatures and good heat delivery material and on the other hand not expensive.

These design requirements are met in each part (step) of the system: they are 4 steps:

1- Shredder (HDPE plastic pieces).

2- Pyrolysis (Soda Can Stove-Aluminum Chamber-Aluminum tube-2 beakers of autoclave material (with glue)).

3- Condensation (Copper Tube-Plastic Tube and Box).

4- Refining.

- In the shredder stage: The plastic waste is shredded into very small pieces; each piece is less than or equal to 1 cm.

- In the pyrolysis stage: The smaller pieces of plastic are then sent into an aluminum round design chamber with a flat base and top having an outer diameter of 13 cm and an inner diameter of 10 cm, an outer height of 7 cm, and an inner height of 5 cm, the thickness of 1.5 cm and 2.2 cm hole at the top connected to a total aluminum tube of 43 cm divided into three parts:

    - The first part is 10 cm connected to the chamber with an angle of 25º.

- The second part is 4.5 cm connected to the first part with an angle of 90º.
- The third part is 28.5 cm connected to the second part with an angle of 155º and the 18 cm beaker with an angle of 90º. (16 cm above the beaker, 3 cm as a connecting part to the beaker, and 9.5 cm under the beaker cover).

where the pyrolysis takes place, the plastic is heated by a Soda Can Stove at a temperature of 800-1000ºC in the presence of a catalyst (Aluminum Silicate Hydroxide Kaolin $Al_2Si_2O_5(OH)_4$) and absence of oxygen. The plastic is slowly melted and converted into a gaseous state.

- In the condensation stage: The gas travels from the aluminum tube to a water and air condenser (12×15 plastic box) through a 3.5 meters copper tube with a diameter of 1.2 cm approximately 0.25 inches connected to a 16 cm beaker (where the condensation process takes place.)

- The Copper tube wrapped 6 rolls each roll 15 cm in diameter.

- In the refining stage: The liquid is sent into the 14 cm beaker.

The free gas or waste heat produced is flowed through a 2 meters plastic tube to be reused and directed to the flame again.

Selection of Solution:

The worldwide plastic generation expanded over years because of the various applications of plastics in numerous sectors that caused the accumulation of plastic waste in landfills. The growing plastic demands affected the petroleum resources availability as non-renewable fossil fuels since plastics were petroleum-based materials.

Few options that have been considered for plastic waste management were recycling and energy recovery techniques, Nevertheless, several obstacles to recycling techniques such as the need for a sorting process that was labor-intensive and water pollution that lessened the process sustainability. As a result, plastic waste conversion into energy was developed through innovation advancement and extensive research.

(Tullo, A.H. 2018).

Since plastics were part of petroleum, the **oil** produced through the pyrolysis process was said to have a high calorific value that could be used as an **alternative fuel**. Plastic wastes can be turned into valuable energy since they are derived from a petrochemical source which having significant calorific value. The conversion can be made possible through several thermal treatment technologies such as gasification, **pyrolysis**, plasma process, and incineration.

Among all these methods, **pyrolysis** is the most desirable process since the initial volume of the waste is significantly reduced, more energy can be recovered from the plastic waste by producing a variety of products, requires lower decomposition temperature, and low capital cost.

Pyrolysis is the process of thermally degrading long-chain polymer molecules into smaller, less complex molecules through heat. The process requires intense heat with a shorter duration and in absence of oxygen.

The three major products that are produced during pyrolysis are oil, gas, and char which are valuable for industries, especially production and refineries.

Pyrolysis was chosen since the process can produce a high amount of liquid oil up to 80 wt% at a moderate temperature of around 800-1000ºC. The liquid oil produced can be used in multiple applications such as furnaces, boilers, turbines, and **diesel engines** without the need for upgrading or treatment. (Sharuddin, S. D., Abnisa, F., Daud, W. A. & Aroua, M. K. 2018).

Parameters play a major role in optimizing the product yield and composition in pyrolysis. Several parameters influence liquid oil production in pyrolysis such as (1) type of plastic, (2) temperature, (3) pressure, residence time, (4) type and rate of fluidizing gas, and (5) catalyst selection.

1. The fuel properties of the liquid oil produced in the pyrolysis process vary according to the chosen type of plastic. The experimental calorific value of HDPE is above 40 MJ/Kg and was considered high for energy utilization.

2. In the thermal degradation of plastics, the temperature is one of the most significant operating parameters in pyrolysis since it controls the cracking reaction of the polymer chain. Different plastics have different degradation temperatures depending on the chemical structure. For HDPE (the type of plastic chosen) the thermal degradation temperature is 800-1000ºC.

3. Furthermore, pressure and residence time also governed the performance of the pyrolysis process. Pressure and residence time are both temperature dependence factors that may have a potential influence on product distribution of the plastic pyrolysis at a lower temperature.

4. The type and rate of fluidizing gas used during pyrolysis also influenced the pyrolysis product. Fluidizing gas is an inert gas (also known as carrier gas) that is only engaged in the transportation of vaporized products without taking part in pyrolysis. There are many types of fluidizing gas that can be used for plastic pyrolysis such as nitrogen, helium, argon, ethylene, propylene, and hydrogen. Each type of fluidizing gas has different reactivity based on its molecular weight. Nevertheless, of all those gases, nitrogen was commonly used by most researchers as fluidizing gas in plastic pyrolysis since it was easier and safer to handle than the high reactivity gas like hydrogen.

5. As for the catalytic degradation, the catalyst is used in the thermal process to speed up the chemical reaction and improves the hydrocarbon distribution to obtain pyrolysis liquid that had similar properties to the conventional fuel such as gasoline and diesel. The three types of catalysts that are widely used in plastic pyrolysis are zeolites, fluid cracking catalyst (FCC), and silica-alumina catalysts. The usage of zeolite catalyst (the chosen catalyst) in pyrolysis of real municipal plastic waste may also help to reduce the impurities in the oil produced.

Selection of Prototype:

The system consists of:

- **A soda C**an **S**tove with a diameter of 4.7 cm and a height of 4 cm heats an
- **A**luminum round design chamber with a flat base and top having an outer diameter of 13 cm and an inner diameter of 10 cm, an outer height of 7 cm and an inner height of 5 cm, thickness of 1 cm, and a 2.2 cm hole at the top connected to a total
- Aluminum Tube of 43 cm divided into three parts:

  - The first part is 10 cm connected to the chamber with an angle of 25º.
  - The second part is 4.5 cm connected to the first part with an angle of 90º.
  - The third part is 28.5 cm connected to the second part with an angle of 155º and the 18 cm beaker.

- **B**eakers (One is 500 ml and the other is 250 ml) connected to a
- **W**ater and air condenser (12×15 plastic box) through a 3.5 meters copper tube with a diameter of 1.2 cm approximately 0.25 inch connected to the 18 cm beaker from one side and the 16 cm beaker from the other side by
- **C**opper tube wrapped 6 rolls each roll 15 cm in diameter.
- **W**ater bottle to absorb carbon dioxide emissions.

1- Time: it becomes short by choosing the shortest dimensions (4.7 cm, 4 cm, 5 cm, 10 cm, and so on) for the volume of the chamber to ensure the speed of the arrival of outputs to their storage positions.

2- Cost: the short dimensions also can decrease the cost in addition to the inexpensive and cheap materials used (Aluminum, Pepsi can stove (waste), Copper, autoclave beakers).

3- Efficiency: the chosen materials have high qualities and low cost. That can help to prevent any emissions or leakage and maintain the quality, purity, and effectiveness of the products.

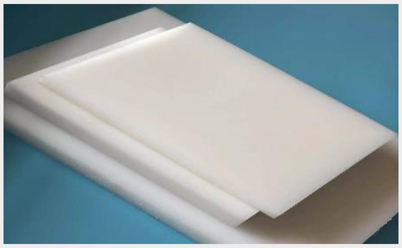
The efficiency of the project depends on these three requirements and they can be tested by calculating the time taken and the cost and comparing them with the previous trials of HDPE pyrolysis under a temperature of 800-1000ºC.

In addition to calculating the system's productive efficiency using this formula: $\frac{Output\ (grams)}{Input\ (grams)} \times 100$

lll. Construction and Testing a Prototype

Materials and methods:

Table (1) The Materials and tools that were used

Items	**Quantity**	**Description**	**Uses**	**Cost**	**Source of purchase**	**Picture**
High-density Polyethylene plastic (HDPE)	13.5 grams	It is a type of plastic that is derived from ethylene and manufactured through low pressure and has a chemical formula of (C_2H_4) n.	Used in: packaging, toys, housewares, grocery bags, and wire insulation.	—	Brought From the unwanted and useless plastics at home.	 
Aluminum oxide metal tubes		It's a light metal that conducts heat & electricity. It resists corrosion and has high stiffness.	Used in: refractories, ceramics, polishing, and abrasive applications. Conduction of thermal energy during the process without being lacking.	240 L. E	Blue Metal shop	
Can stove	2 can stoves	It's can base alike stove the internal thermal energy is ranged from 800-1000◦c.	Used for: pyrolysis, heating substances, and cooking.	They're manufactured manually through using 2 can base and perforate specific regions in them,	—	

Aluminum Silicate Hydroxide Kaolin ($Al_2Si_2O_5(OH)_4$)	4 grams	It is a chemical material related to Zeolite family and can fasten the reaction with the smallest amount possible &without participating in the reaction at all	Used in: Catalytic purposes as it has high efficiency when it's used as catalyst, cracking, isomerization, and hydrocarbon synthesis.	It is borrowed From the Scientific Research and Technological Applications Institute.	Scientific Research And technological Applications Institute.	
canisters (Autoclave material)	2 canisters	They're canisters having different sizes with high durability and withstanding extremely high temperatures. There are made of autoclave glass.	Used in: Producing, heating, or preserving something from being exposed to the external high temperature.	155 L. E	The medical crescent shop	
Aluminum Chamber	1	A chamber is made of the same material as the tubes (Al_2O_3 bars) To allow the heat to be stored through the tubes.	Used in: thermal energy isolation that is produced throughout pyrolysis.			

Copper Tube		Soft and malleable; a freshly exposed surface has a reddish-orange color that conducts heat & electricity. It resists corrosion and has high stiffness.	Used as a good medium for thermal exchange and gas transportation from one container to another.	140 L. E	—	

Methods:

A chamber that is made of aluminum is used for gathering polyethylene (the useless plastic by-product) till it becomes filled with 13.5 gm of plastic. A chemical material that has the capability of acting as a catalyst is called (aluminum silicate hydroxide kaolin) which resembles the characteristics of zeolite (a chemical substance used as a catalyst for most reactions). Its chemical formula is
$(Al_2Si_2O_5(OH)_4)$ as it is composed of 2 atoms of Aluminum, 4 of Hydrogen, 5 of Oxygen, and Silicon. The cracking catalytic aluminum silicate is used for promoting and inducing the speed of chemical reactions.

The chamber is placed on a can stove to perform a pyrolysis process ranging from 800° to 1000°, the material which has been chosen specifically to be used in preparing the beaker and tubes is Aluminum due to its capability of storing the thermal energy generated through pyrolysis process inside the beaker. After that, a tube of the same material is welded to the lid of the beaker and that of the first container with definite and measured angles in an accurate method. The premiere duct should be inclined with 25° as it is considered the most optimal angle to let the gas produced via combustion flows directly without procrastination or consuming long periods as time is one of the design requirements that one should be aware of. The second part of the trough is inclined with 155° according to various estimations and measurements. Furthermore, the two segments of the tube have the same length which is 15cm. a small segment of the tube is welded with the lid of the diesel container (collector) to let the heated gas exit it producing diesel precipitating at the bottom of the vessel.

The beakers are made up of a certain type of glass which is called (autoclave), it’s characterized by various perks and utilities. For instance: having substantial and tremendous endurance of high-temperature degrees, therefore there will be feelings of safety and satisfaction during applying the process with the least dangers possible. The diesel is gathered at the bottom of the canister, while the fuel gas will continue its flow path to the second container.

The second one contains ice or water with the least degree possible to condense the fuel gas as the massive difference in the temperature degrees leads to condensing the gas passing through the pipe, the next step, another material is used which is: copper. Copper has bendability and malleability, so it is coiled around a cylindrical-shaped thing with a diameter of 1.2 cm.

The reminded part of the copper tube has pertained to the last vessel that contains water. Water has been in the consideration to absorb all the mischievous gases resurrected throughout the entire process, eventually, hazardous gases especially carbon dioxide gas have been got rid of through a long plastic tube that transfers the useless gases to the chamber again to bestir the plastic pyrolysis to be increased in the rate, so the process will be fastened and the desired products (fuel gas and diesel) are devoid of those gases.

Test Plan

The test met all the design requirements we had chosen.

- Instead of 10 minutes, the process took only 7 minutes to produce the required products (diesel and fuel oil).

As a byproduct, we employ HDPE plastic. Food packaging, bottles, bags, drums, gasoline tanks, and other automotive parts, pipe, film, geomembranes, toys, and filament are all common uses for HDPE. So, it is available frequently, which makes it extremely efficient so the efficiency is excessively high: $\frac{Output\ (grams)}{Input\ (grams)}\times 100$

These design requirements are met in each part (step) of the system: they are 4 steps:

1- Shredder (HDPE plastic pieces). 2- Pyrolysis (Soda Can Stove-Aluminum Chamber-Aluminum tube-2 beakers of autoclave material (with glue)). 3- Condensation (Copper Tube-Plastic Tube and Box). 4-Refining.

We made three trials (for an efficient test):

- The first trial: To speed up the process, waste plastic is collected and shredded is used. A sample of discarded plastic (HDPE) weighing 13.5 grams is obtained and cleaned. The sample is placed in the reactor and heated to 800-1000ºC for <u>10 minutes</u>, after which the diesel gas is created, however, our goal is to shorten the duration.
- The second trial: We repeated the technique, but this time we utilized a catalyst (aluminum silicate) to speed up the reaction, which was already efficient. It only took <u>8 minutes</u> to complete the reaction after applying it.
- The third trial: The chamber in the last two experiments had a flat base and top with a diameter of 10 cm, a height of 5 cm, and a thickness of 1 cm. However, for the third time, we utilized a smaller thickened one (0.2 cm) that concentrated all of the heat on the chamber, allowing the plastic to evaporate faster, taking only <u>7 minutes</u>.

  According to table (2) and the 3 trials shown in, the results show that

HDPE is broken down relatively quickly and after about (7-9) minutes very little of the HDPE is left. The conversion of both heavy wax and light wax begins when the majority of the HDPE has been broken down. The production of oil and gas is rapid in the initial phases of the process and begins to level off as the light and heavy wax produced in the early phase of the process is used up.

Table (2) Taken time for each trial

Trial (NO)	*Temperature (ºC)*	*Time (minutes)*
Trial 1	800	9
Trial 2	800	8
Trial 3	800	7

When the temperature gets 800ºC:

1- The first trial took 9 minutes, and then the products are produced.
2- The second trial took 8 minutes to start producing.
3- Unlike other outputs, the third trial took 7 minutes.

The presented results are consistent with the literature.

After approximately 2 hours, there is roughly 80.9wt% oil and 1.9wt% gas. The remaining 17.2wt% is carbon black.

Table (3) Products Yield of HDPE pyrolysis

Products of HDPE pyrolysis	*Oil (Diesel)*	*Gas*	*Char (Carbon Black)*
Percentage Yield (wt%)	80.9	1.9	17.2

Table (4), clearly depicted that the physical properties of plastic pyrolysis oil were very close to the properties of commercial gasoline and diesel. Therefore, plastic pyrolysis oil has a very high potential to be used as a new energy resource.

Table (4) Physical properties of plastic pyrolysis

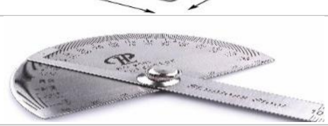
Property	**Unit**	**Diesel**	**HDPE pyrolysis oil**
Calorific Value	MJ/kg	45.8	46.2
Density	g/cm^3	0.7994	0.8147
Flashpoint	ºC	70	100

Data Collection

Table (5) Precision and accuracy of measurements

Tool	Length	Width/Diameter	Height	Thickness
Soda Can Stove	-	(4.7±0.001) cm	(4±0.001) cm	(0.1±0.001) cm
Aluminum round design chamber	-	Outer: (13±0.001) cm Inner: (10±0.001) cm	Outer: (7±0.001) cm Inner: (5±0.001) cm	(1±0.001) cm
Aluminum Tube	(43±0.001) cm	Outer: (2.5±0.001) cm Inner: (2.4±0.001) cm	-	(0.1±0.001) cm
Autoclave beaker 1	-		(18±0.001) cm	
Autoclave beaker 2	-		(14±0.001) cm	
Copper Tube	(3.5±0.001) m	Outer: (0.635±0.001) cm Inner: (0.51±0.001) cm	-	(0.125±0.001) cm
Plastic Box	(12±0.001) cm	(15±0.001) cm		(2±0.001) cm

Table (6) Measurement Tools

Measurement Tools	Picture	Absolute Error
Digital thermometer		(±0.001) °C
Digital Caliper		(±0.001) cm
Digital scale		(±0.001) g
Protractor		(±0.01°)

After putting the prototype in its standard (vertical) position above the heat source, 1- The plastic pieces were weighed in addition to the catalyst using a digital scale to determine the weight of the outputs according to the law of conservation of mass.

2- The value of the angle of the output exit tube (25^{o}) has been confirmed using the protractor to ensure the quality of the outputs.

3- The timer was turned on at the beginning of the reaction to calculate the time it took to start (target design requirement).

4- The temperature used to compare the outputs of the solution with the prior ones at the same temperature, to determine the efficiency of the process, was calculated using a thermometer.

The process is initiated by fetching an Aluminum chamber with a diameter base (13±0.001) cm and (7±0.001) cm height to be put on two Soda cans stove with diameter (4.7±0.001) cm and 4cm height.

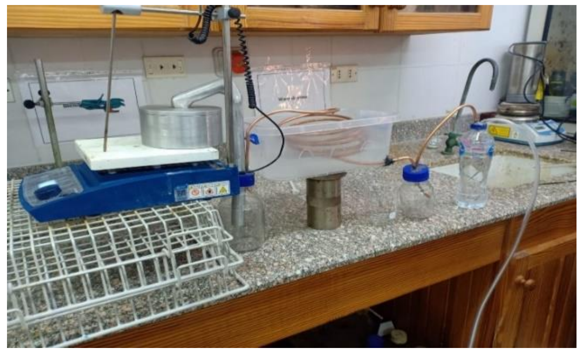


Fig (23) Selected Prototype

Inside the chamber, polyethylene plastic (HDPE) exists weighing (130.5004±0.001) g until the chamber is heaped, then (12.9477±0.001) g of Aluminum Silicate Hydroxide Kaolin ($Al_2Si_2O_5(OH)_4$) is added to it due to its catalytic characteristics, it can speed up and promote the chemical reaction as this causes efficiency augmentation. Then, the Pyrolysis process is involved through the process to burn the plastic resulting in fuel gas with 1.9wt% (2.47g), char with 17.2wt% (22.36g), and diesel with 80.9wt% (105.17g), so the char precipitates in the chamber, while fuel gas and diesel pass via the Aluminum tube which is welded at the center of the chamber lid with (2.5±0.001) cm diameter and is inclined with angle 25^{o} to assist the products to flow fast and smoothly. The diesel condenses at the bottom of the first autoclave glass beaker with 18cm height, another tube is pertained to the beaker’s lid descending with 155^{o}, and fuel gas passes through the tube to collide with ice in the container to transubstantiate it into fuel oil. An auxiliary bottle of water is put in to absorb any useless gas, especially carbon dioxide in order not to contaminate the atmosphere.

IV. EDP Progress: Evaluation, Reflection, Recommendations:

Analysis and Discussion

The results of HDPE pyrolysis show higher liquid and solid yield (80.9wt%-17.2wt%), but lower oil yield (1.9wt%). However, the design requirements (time (7 minutes)) have been met with a high degree of efficiency (compared with the prior ones (liquid yield 68.5wt%, oil yield 31.5wt%, and solid yield 0wt% in (20-25 minutes)). (Positive points).

CO_2 emissions (219g) from ethanol (combustion (ethyl alcohol) and the enthalpy change happened represented (Negative points):

$$C_2H_5OH_{(l)} + 3O_{2(g)} \rightarrow 2CO_{2(g)} + 3H_2O_{(g)}, \triangle H = -1367 kJ/mol$$

As **Figure (24)** suggests, ethanol combustion is an exothermic reaction where the heat content of the products is less than that in the reactants ($\triangle H$=negative value).

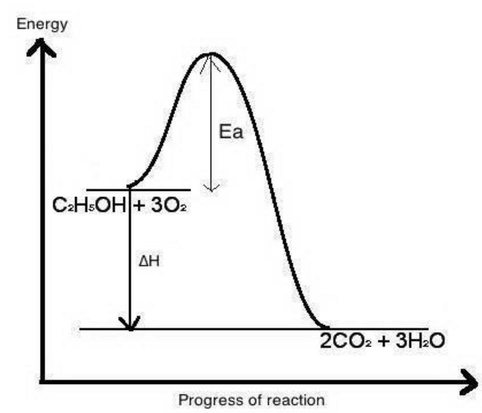


Fig (24) Exothermic Reaction

The pyrolysis process contains some important steps. As shown in **Figure (25)**, the plastic must first be processed into small pieces, preferably 5 mm. This is to ensure high thermal convection as possible and a good distribution of heat.

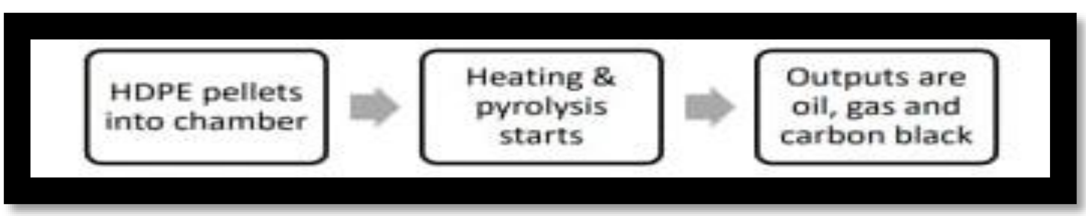


Figure (25) The basics of the pyrolysis process

The pieces are then heated with a catalyst (Aluminum Silicate Hydroxide Kaolin ($Al_2Si_2O_5(OH)_4$)) by a soda can stove in a chamber to around 800°C – 1000°C to begin the pyrolysis process using an external source of renewable fuel (ethanol C_2H_5OH). Once this temperature is reached, the gasses that are being produced by the pyrolysis reaction form the primary fuel for the external burners.

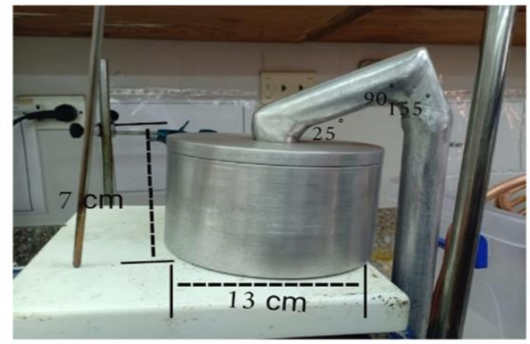


Fig (26) The chamber and the tube design

As **Figure (26)** suggests the chamber is a round design made of aluminum with a flat base and top having an outer of (13±0.001) cm, an inner diameter of (10±0.001) cm, an outer height of (7±0.001) cm, an inner height of (5±0.1) cm, and a thickness of (1±0.001) cm, subjected to a hole having a diameter of (2.2±0.001) cm at the top connected to a total 43 cm aluminum tube. This is to increase the total surface area of the chamber ($100\pi=314.2\pm0.6$) cm² and the volume ($125\pi=392.7\pm0.9$) cm³ to make the chamber capable of accommodating a large amount of HDPE pieces compared with the cuboid chamber. The atmosphere inside the chamber is normally inert to prevent unwanted reactions taking place. During pyrolysis, explosions and fires are an obvious risk because the chamber contains flammable oils and gasses. To limit the risk of explosions and fire, nitrogen (N_2) is recommended to be pumped into the reaction chamber before heating. As the pyrolysis process progresses, the oil will flow from the chamber to storage. The time to ensure complete conversion of the plastic will vary depending on the molecular structure of the plastic, but for 5 mm pieces of HDPE (C_2H_4), the time is around 7 minutes. In addition to the angle of the connected aluminum tube. The aluminum tube is 43 cm divided into three parts: The first part is 10 cm connected to the chamber with an angle of 25°. This is for two reasons:

1. To reduce the value of the slope that the liquid and gas ascend with, and thus increase the speed of its flow and reduce the time.
2. In order not to hinder the gas movement as in the right angle (90°) so it is not recommended.

The second part is (4.5±0.1) cm connected to the first part with an angle of 90°.

The third part is (28.5±0.1) cm connected to the second part with an angle of 155º and to the 18 cm, a beaker with an angle of 90º divided into 16 cm above the beaker, (3±0.001) cm as a connecting part to the beaker and (9.5±0.001) cm under the beaker cover as **Figure (27)** suggests.

The fuel gas produced from the aluminum tube moves from the high-pressure region to the low-pressure region, that's why the aluminum tube is made longer.

Fig (27) First Beaker mechanism

In the condensation stage: The gas travels from the al aluminum tube to a water and air condenser (12×15 plastic box) through a (3.5±0.001) meters copper tube with a diameter of (1.2±0.001) cm approximately (0.25±0.001) inch connected to a (14±0.001) cm beaker (where the condensation process takes place) as **Figure (28)** suggests. This is to increase the velocity of the gas produced according to the continuity equation: $AV = constant$.

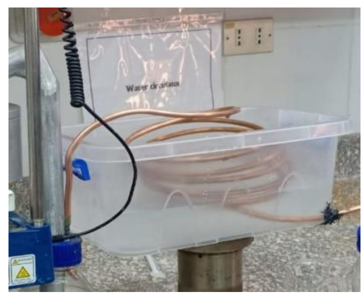


Fig (28) Condensation stage

The Copper tube wrapped 6 rolls each roll 15 cm in diameter. This is to increase the area for the fuel gas to be condensed. The gas produced at high temperature (800°C – 1000°C) is exposed to a very low temperature (Freezer temperature). This is to increase the condensation process by increasing the change in temperature (Δt) to increase the heat added or lost (Q) as the specific heat capacity for fuel gas= 2200 J/g K is constant and the mass also is constant according to this formula: $Q = mc\Delta t$ **is the equation for specific heat.** Specific heat is the amount of heat per unit of mass that is needed to raise the temperature of the substance by 1 degree Celsius. Q represents the heat lost, c is the specific heat of the substance, m is the mass of the sample, and Δt (delta t) is the change in temperature, but at the point of condensation, this equation doesn't work because the material state is changing. The equation followed then is: $Q = mL$ L is the latent heat.

In the refining stage: The liquid (condensed fuel oil) is sent into the 14 cm beaker as **Figure (29)** suggests.

Fig (29) Second Beaker Mechanism

It is recommended that: The expansion in volume that happened to the chamber must be calculated first to know if the initial number of plastic pieces can expand or not (for safety). According to this formula: $\triangle V = \beta V_1 \Delta t$ where β is the material volumetric expansion coefficient.

This part is made for two reasons: 1. To take advantage of the free gas or waste heat produced which is flowed through a 2 meters plastic tube to be reused and directed to the flame again as **Figure (30)** suggests. 2. To absorb CO_2 emissions from the combustion reaction happened.


Fig (30) Water Bottle for CO_2 emissions

Recommendations

1- Using a catalyst (zeolite) to lower the activation energy needed for the reaction
2- Making the exit angle of the products (25^{o}) to reduce the value of the slope through which the gas and liquid will exit, and therefore one will not hinder the movement of the other.
3- Use nitrogen (N_2) in the beginning so that there will be no emissions in the other.
4- In the state of unavailable nitrogen, it can be replaced with a water bottle at the end to absorb the emitted carbon dioxide (CO_2).
5- Using (microalgae) for carbon dioxide emissions.
6- It is recommended to rely on (solar energy) as a source of heat at the beginning instead of the spark.
7- Taking into account the reasons for safety and security due to the high temperature
8- Taking into account that the beakers used must be made of materials that are resistant to heat and high pressure (such as the autoclave material used).
9- Add (calcium bentonite) to plastic while fission it to evaporate quickly and not consume much energy in the process of converting it into fuel gas.

Learning Outcomes

PH.1.08: It is learned how to take advantage of using the pressure difference between two points of fluid in the lengths of tubes that gases come out from and go through.

PH.1.09: It is learned to apply principles of fluid dynamics (the continuity equation) in determining the area of the cross-sections of the tubes.

PH.1.09: It is learned to use general properties of fluids (velocity, pressure, volume and temperature relation, viscosity, and compressibility) that’s why the exit angle of the products of the tube is made 25^{o}.

PH.1.09: It is learned how to use the continuity equation: $AV = \ constant$ in increasing the velocity of fluids by decreasing the area of the cross-section and vice versa.

PH.1.10: It is learned to design a system for efficient energy production using concepts of specific heat capacity in determining the suitable material for the process by determining the amount of heat needed using the formula: $Q = mc\Delta t$.

PH.1.11: It is learned to analyze energy flow in typical heating and cooling applications by applying the conservation of thermal energy and Energy graphs.

CH.1.08: It is learned to explain how the chemical and physical properties of solutions, suspensions, colloids, and Nano substances can be used in water treatment for the condensation process happened.

CH.1.10: It is learned to calculate quantities of products formed from known quantities of reactants and be able to discuss their precision and accuracy in the ethanol combustion reaction to know what amount of carbon dioxide can be produced to provide possible ways of absorption.

$$C_2H_5OH_{(l)} + 3O_{2(g)} \rightarrow 2CO_{2(g)} + 3H_2O_{(g)}, \triangle H = -1367 kJ/mol$$

CH.1.11: It is learned to investigate four types of chemical reactions to know which reaction your process includes to be able to identify the products and if the reaction is redox or not.

CH.1.15: It is learned to determine, explain and illustrate how energy and disorder change during physical and chemical processes using the concepts (system, heat content, endothermic, and exothermic) to determine the type of reaction based on the heat content of the system and the surrounding environment.

CH.1.15: It is learned about enthalpy change the heat of the reaction of the chemical reaction and how the difference between the heat content of the reactant and the heat content of the products is.

CH.1.15: It is learned about the activation energy and how to decrease it to decrease the time needed for the reaction to occur by using a catalyst (Aluminum silicate $Al_2Si_2O_5(OH)_4$) and the concept of the activated complex.

CH.1.16: It is learned to use the Gas Laws to explain the principles of SCUBA diving.

MA.1.08: It is learned to create, interpret and analyze exponential and logarithmic functions that model real-world situations to inform alternative energy geometries, using graphs.

ES.1.10: It is learned to evaluate potential renewable energy sources in Egypt to replace dependence upon fossil fuels to give an idea for the system's design to be built.

ES.1.11: It is learned to recognize the processes by which fossil fuels (coal) are extracted and processed for human use which leads to the idea of reversing the process of plastic production to get fuel at the end as a kinetic energy resource.

BI.1.11: It is learned to Create your experiment to investigate a factor, that affects that helps a lot in comparing and contrasting the design of a test plan for the prototype.

BI.1.14: It is learned to analyze how natural and human-caused events can unbalance an ecosystem and how can the prototype design can help prevent this unbalance.

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