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作品名稱　Using P.I.P. to strengthen roads: Plastic incinerated by plastic

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1. Introduction

People have become accustomed to single-use plastics. These are plastics that are used once only and are then thrown away or recycled. A piece of plastic can only be recycled 2-3 times before it is of bad quality and can no longer be of use. (Achyut K. Panda, 2019). Plastic waste fills up landfills and oceans, becoming hazardous and harmful to wildlife, while emitting greenhouse gasses. Alternatives, such as metal straws and paper bags have turned out inefficient and plastic is still a great need in society.

Another way of getting rid of waste plastic is to burn it. Fossil fuels such as coal and natural gas are being utilised to burn plastic in industry. This causes many harmful emissions, such as carbon dioxide and carbon monoxide released from burning the plastic. It results in more damage being done than just leaving the plastic in a landfill. These emissions can be cleaned before being released into the atmosphere. Plastic is made of petroleum, so when it is burned it is converted back into a fuel. Plastic can be burned under controlled conditions to create a fuel source that can be used, thereby utilising the waste plastic. The research conducted aims to investigate the use of plastic waste to burn other plastic to create a renewable fuel source and to eliminate plastic waste.

Additionally, asphalt is a petroleum-based liquid that is used to build roads. There are roads of inefficient quality as they crack easily and have many potholes. Solid plastic waste can be added to asphalt to tar the roads. It makes the roads stronger and more durable. (V. Tare, 2014). The research conducted aims to investigate how the addition of the solid waste produced from burning plastic can increase the strength of asphalt.

(New areas of research added investing the addition of the solid plastic waste to asphalt in the project is written as "**additional experimentation"**, for example there is an original hypothesis and an **additional hypothesis**)

2 Literature review

2.1 How are plastics turned into fuel?

Throughout the world, one million plastic bottles are purchased every minute. Five trillion plastic bags are produced worldwide each year. Only 8.7% of plastics are recycled. Reasons vary from the cost to recycle to recycling being a complicated process (UN Environment reporter, 2018).

Plastics are hydrocarbons that can be made from petroleum (C2H4) and can be converted back to liquid fuel. The process is known as pyrolysis which is the thermal degradation of plastic waste at different temperatures (300–900°C), in the absence of oxygen. This turns the plastic into a gas which is then condensed to form liquid fuel. Jayme Navarro, founder of Poly-Green Technology and Resources was the scientist who discovered this process. Different kinds of catalysts, such as zeolite are used promoting process efficiency, targeting the specific reaction, and reducing the process temperature and time. The temperature, time and catalyst used affects the product produced from the reaction (Wei-Hesin Chen, 2019).

Plastic fuel produced from pyrolysis is flammable. At optimum conditions, more than 79% yield of oil is obtained. The calorific values were similar to the heating values of conventional fuel/petroleum and fuel oil product from plastics pyrolysis reported by many studies, including "Science Direct" which are within the range of 33.6–53.4 MJ/kg, depending on the original plastic polymer composition (R.Thahir, 2019). These studies demonstrate production of liquid fuel from plastic waste using this method is feasible to be applied.

2.2 Why are all plastics not recyclable?

Recycling certain plastics are not economical or environmentally friendly. Some products should not be put in recycling bins, such as thin plastics which can clog the processing machinery when it is recycled with larger, rigid plastics. Every day about 8 million pieces of plastic waste make its way into the oceans. It costs money to pick up, transfer and process the plastic waste for recycling. Some countries have numbers on the plastic which mark what type of plastic it is and whether it can be recycled. This is known as Resin Identification codes (RIC).

Table 1: Resin Identification Codes and examples of each type.

1. Polyethylene Terephthalate (PET) – drink bottles and cups.
2. High-Density Polyethylene (HDPE) - bottles, cups, and milk jugs.
3. Polyvinyl Chloride (PVC) - rigid plastics like pipes and tubes.
4. Low-Density Polyethylene (LDPE) - beer six-pack fasteners and plastic bags.
5. Polypropylene (PP) - food containers and some plastic car parts.
6. Polystyrene (PS) - used to hold food, drinks cups and some plastic utensils.
7. 'Other' – general purpose category for acrylic, nylon, and other plastics.

The lower RIC numbers (1-4) as seen in Table 1, are easy to recycle. It becomes less possible to fully recycle plastics after the RIC number 4 (Lucy V, 2018).

2.3 Emissions released from pyrolysis

Pyrolytic gasification is where the plastic is heated at high temperatures (160º - 210º Celsius) in a completely oxygen-free environment. There are emissions (refer to table 2) that are produced when the plastic is burnt in the open air. Pyrolysis causes the plastic to become a gas, which is then mixed with air before it is burned as a clean fuel. This method will decrease the emissions caused by burning plastic so that it does not damage the environment.

When a fuel, such as coal and natural gas, there are added emissions (namely carbon dioxide) from these fuels. The table below shows the gases produced through plastic pyrolysis. (J Environ Public Health, 2016)

Table 2: Gases produced through plastic pyrolysis

hydrogen	H_2
carbon dioxide	CO_2
carbon monoxide	CO
methane	CH_4
ethane	C_2H_4
butadiene	C_4H_6
propane	$CH_3CH_2CH_3$
propene	$CH_3CH=CH_2$
n-butane	$CH_3(CH_2)_2CH_3$

Burning plastic also releases dangerous chemicals such as hydrochloric acid, sulphur dioxide, dioxins, furans, heavy metals, as well as particulates. These emissions can cause respiratory ailments and stress human immune systems and are potentially carcinogenic (Amy Miller, 2013).

The pyrolysis yield depends on several parameters such as temperature, heating rate, moisture contents, retention time, type of plastic and particle size. A yield of up to 80 % of liquid fuel by weight can be achieved from plastic waste. The produced liquid fuel has similar characteristics to conventional diesel; density (0.8 kg/m^3), viscosity (up to 2.96 mm^2/s), and energy content (41.58 MJ/kg) . (Ismail I.M, 2016)

How to clean the emissions?

The syngas (synthetic gas emitted as seen in table 2) should be burnt at high temperatures before being released. This eliminates the harmful particles, and the final exhaust gas is clean of the heavy molecules and particles of plastic. The syngas can also be recycled through the system. This is when the gases are not released into the environment and are used as part of the fuel to burn the plastic. These gases are high in energy and can provide energy to the system. This saves cost and optimises production, while also eliminating the harmful particles.

2.4 How is this research different?

The burning of plastic has been done using a fuel, such as coal or gas. This is costly but produces a certain type of fuel, such as diesel or petrol. This is achieved by heating the plastic to a certain temperature to produce a gas that will be condensed to create a specific fuel. The fuel will vary depending on the temperature, the catalyst used, and the type of plastic being burned.

In this investigation, plastic fuel that is produced when plastic is burned, will be used to burn more plastic. This will be cheaper as there will be no catalyst needed and the all the plastic will be heated to form one oil, not many different specific fuels. The companies that are burning plastics to create a fuel are making profit of this fuel. Thus, they will continuously want more of the same plastic for this fuel. This need might incentivise plastic companies to start producing more plastic as there is a need for this. A higher production of plastic will also lead to more pollution.

The research in this investigation is being carried out to produce a fuel to burn plastic, creating a system where the plastic eliminates itself. This decreases pollution and puts the environment and its inhabitants at less of a risk. This is due to the plastic being effectively utilised and its by-products (emissions, section 2.3) treated, ensuring the environment is safe.

Additionally, this research goes on to investigate the waste products of plastic burning. Plastic has been added to asphalt as a whole, not just the remaining carbon waste product left after burning the plastic. The solid plastic waste was also mixed with the filtered gas emissions to remove the emissions. This had not been done before and was not used in asphalt before.

2.5 Advantages of using plastic fuel to burn plastic:

- Majority of plastic is not recyclable, and this is the reason that there is large amount of plastic waste in oceans and landfills. The plastic waste is very harmful to all life forms and the environment. Burning the plastic will remove it from the landfills and will decrease the amount of physical land pollution.
- The fuel that is produced would have been used as a source of energy increasing the amount of plastic needed. Using plastic fuel to burn more plastic will be a continuous cycle of eliminating plastic waste until it is completely gone.
- Using this fuel will be cheaper than using an external fuel, such as coal and natural gas. No catalyst will be needed to create a specific fuel as all the plastic will be burnt into one fuel and this fuel will be used to burn more plastic. The emissions that would have been created from burning an external fuel (usually fossil fuels) will no longer be an issue as there will just be emissions from the plastic.

2.5.1. Advantages of using plastic waste in asphalt to build roads:

- Roads are damaged easily and are not durable enough, the plastic waste strengthens the asphalt.
- Asphalt with added plastic waste can withstand harsher conditions.
- It is a way to remove the solid and gas waste products produced when making plastic, making the burning of plastic through P.I.P a safer system.
- It is an inexpensive way to strengthen the roads as it is using a waste product and does not need to build or develop anything

2.6 Disadvantages of using plastic fuel to burn plastic:

- Emissions produced can be damaging to the environment. The emissions can be treated but this can be costly.
- Funding will be needed to construct and run this plant.
- But-in from governmental organisations to implement such systems and a “plastic tax” is required to ensure the success of the proposed solution.
- The original plastic fuel will need to be produced by burning an external fuel as a trigger.

2.6.1 Disadvantages of using plastic waste to improve asphalt:

- The plastic waste has to be added to asphalt and cannot be used by itself to build roads.
- There is a limit to how much can be added as it is carbon based and will not mix with water which is required to make asphalt.

2.7 How to test if plastic fuel can replace other fuels in this system:

The plastic gas must reach the same temperatures at similar rates to the coal and the gas. Comparing the temperature against time for coal, natural gas and the plastic fuel will show if the plastic fuel can replace the external fuels in this system. The plastic fuel should be able to melt the plastic at a similar rate to the coal and the natural gas.

(**Plastic gas** is a term used to describe the gas that is produced when plastic is heated above the melting point. **Plastic fuel** is the fuel that is produced when the plastic gas is condensed.)

2.8 What is asphalt?

Asphalt is used to build roads. This is because it is cheaper and easier to install than concrete. Asphalt is a petroleum based semi-solid that is sticky and black. It creates a smooth surface for the road. It can minimise splash and reduce road accidents. Asphalt can be mixed at home with aspahalt cold patches and water to activate it.

2.9 How to test if adding plastic waste to asphalt improves its strength:

Plastic is made of carbon and the residue that remains when plastic is burned is a carbon based solid. Plastic has been mixed with asphalt to make it stronger, this would support the idea that the solid plastic waste can also be used to make asphalt stronger. This can be tested by comparing the strength of normal asphalt with asphalt mixed with different amounts of plastic waste. This will show how much solid plastic waste is the most efficient amount to add to the asphalt. The strength can be tested by drilling a hole into the asphalt and seeing the time it takes. The longer it takes, the stronger the mixture is. This should also be tested in different conditions to see if the different mixtures will be able to withstand conditions of the road.

3. Problem Statement

Plastic is damaging the environment and posing health risks to its inhabitants. It is necessary to find an alternative use for plastic waste rather than landfills as plastic is non-biodegradable. Fossil fuel sources, such as coal and gas are being used as a power source in industry and in various companies. If plastic is burned, it is costly and releases many emissions because of the use of external fuels. It is essential that we reduce plastic waste and the burning of fossil fuels and natural gases. It is necessary to also correlate the time and temperature of burning plastic to that of a fossil fuel, such as coal and natural gas.

Additional problem statement: There is a small amount of gas emissions that remain, even after the gas has been run through the system. This needs to be cleaned. There is a solid waste that remains after plastic is burned. This cannot be used as a fuel and more forms as more plastic is burned.

3.1 Research Question

Primary question: Can plastic waste be used as a substitute to fossil fuel sources to reduce plastic waste?

Secondary question: Will plastic melt at the same temperature and time when being burned by plastic fuel as compared to a fossil fuel. Will it produce a larger amount of fuel when burned by plastic fuel?

Additional question: Can the solid formed from the burning of plastic waste be added to asphalt to improve the quality of asphalt and the durability of roads?

4. Aim

Aim 1: The research aims to demonstrate that the fuel produced when plastic is heated can burn more plastic waste.

Aim 2: The aim will be to see if plastic fuel can be used in place of a fossil fuel, melting plastic at the same temperature and time.

Additional aim: The aim will be to clean the gas emissions and utilize the solid waste.

5. Hypothesis

The plastic fuel will burn the set mass of plastic at a similar time and temperature as when burnt by gas or coal. The plastic fuel will produce a similar amount of fuel from burning plastic as compared to the natural gas and coal.

Additional hypothesis: The addition of the solid plastic waste to the aphalt will improve the strength of the asphalt. The more plastic waste added to the asphalt mixture, the longer it will take to cause a hole in the mixture by drilling it.

6. Variables

The experiment involved investigating two areas with regards to the burning of plastics; therefore, there are two sets of variables as shown in Table 3.

Table 3: Table showing variables

	Set A	Set B
Independent Variable	The type of fuel being used will be changed. (Coal, natural gas and plastic fuel)	The time taken for the fuel to burn the plastic.
Dependent Variable	The volume of plastic fuel produced in each experiment.	The temperature the fuel reaches as it burns the plastic.
Control Variable	• It is in the same vessel • No catalyst or water is added • The type of plastic • The time is the same • The mass, shape, and size of the plastic to be burned.	• It is in the same vessel • No catalyst or water is added • The type of plastic • The mass, shape, and size of the plastic to be burned.

Additional variables: The independent variable is the amount of solid plastic waste added to the asphalt. These are placed under different conditions, one being normal, wet and being hit by a hammer. The dependent variable is the strength of the asphalt, which is measured by time taken to dig a 2cm hole in the asphalt by drilling into it. The control variables are the amount of asphalt used, the drill used, the amount of water added to the mixture.

7. Method

7.1 Materials

- Plastic film (100cm x 80cm)
- Stainless Steel Vessel
- Kettle
- Gas stove (Natural gas)
- Flexible tube (x2 of 300 cm)
- Condenser (50 ml)
- Container of ice (3kg)
- Gas mask and gloves
- Fire Lighter

- Temperature gun
- Coal (500g)
- Kitchen scale
- Screwdriver
- Plastic fuel (can be obtained through burning plastic by coal and natural gas- 90ml will be needed)

For current experiment:

The plastic filmed that was used in each experiment is measured to be 50 grams and is 100cm x 80cm as can be seen in Figure 1, 2 and 3.

The infrared thermometer that was used to measure temperature is a T306 as seen in Figure 4.

The heat conducting container in Figure 5 is an enamel kettle. The condenser shown in Figure 6 has a valve to open and close the flow of the gas or liquid inside.

Figure 1: Thin plastic film 100cm x 80cm

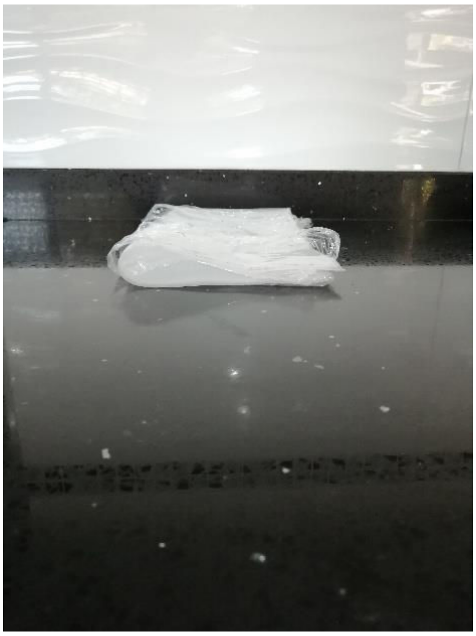


Figure 2: Plastic to be burned

Figure 3: The plastic was measured to be 50 grams.

Figure 4: An Infrared thermometer was used to measure temperature.

Figure 5: A heat conducting container

Figure 6: Condenser with valve

Additional materials:

- Solid plastic waste (150g)
- Water
- Asphalt mixture (3kg)
- Aqueous ammonia (100ml)
- 18 equally sized containers/ buckets
- P.I,P system

7.2 Collection of different types of plastic

In industrial applications, there are various types of plastics which can be used in the pyrolysis process. These vary such as Polyethylene terephthalate (PET), High-density polyethylene (HDPE), Polyvinyl chloride (PVC), Low-density polyethylene (LDPE), Polypropylene (PP) and Polystyrene (PS). (Anandhu Vijayakumar, 2018) The type of plastic been burned determines the quality of liquid fuel produced. If recyclers or suppliers have large quantities of plastic, it is more efficient to use a plastic separation method so that the quality of liquid fuel produced is of a better grade. As such, a mobile application, the PLASTICATOR APP, was developed to obtain information from these providers. The application can be installed on any mobile device and can be used at plastic waste collection sites. The layout of the application is shown in the Appendix. It also allows for monitoring of quantities, suppliers and types of waste been incinerated. This is saved onto a database and can be used for analysis purposes as well. The personal information used in the APP is optional and is used for research purposes only.

The PLASTICATOR APP can be accessed with the following link: https://bit.ly/3lFdFMC

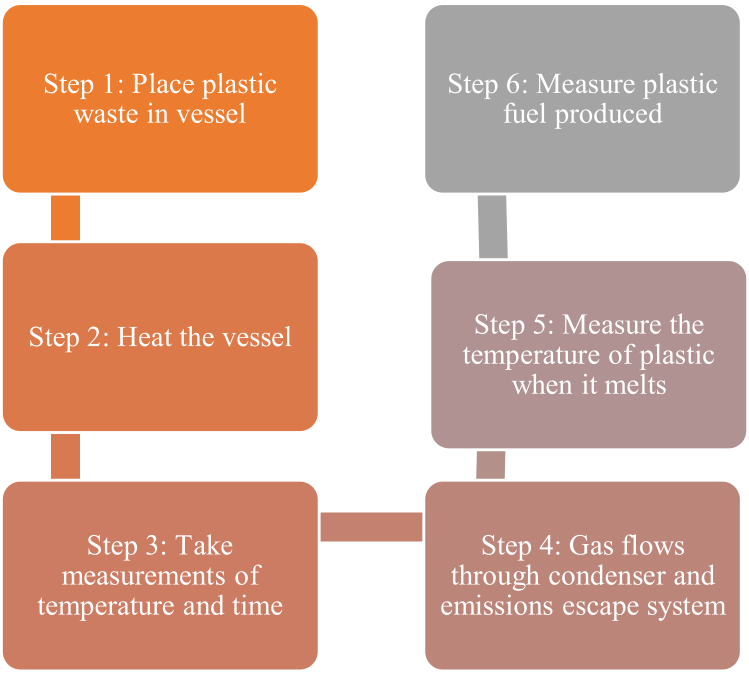
The QR Code below can also be used to access the app:

7.3 Experimental Design

The experiment consists of three trials.

- *Trial 1- consists of only part A, and the experiment could not be continued further.*
- *Trial 2- consists of Part A, B and C. All the fuels were tested.*
- *Trial 3- consists of Part A, B and C. All the fuels were tested.*

The steps of the experiment can be seen in Flow Diagram 1. Small amounts of plastic were burnt during the experiment. This allowed for a small amount of harmful emissions to be produced. For this reason, the syngases were not burnt as there were insufficient emissions to cause damage to the environment. The syngas was not recycled, as the vessel needed to be opened.



Flow diagram 1: Steps of the experiment

<u>Trial 1:</u>

The first trial was to test if the equipment was suitable for burning plastic and what equipment and method would be needed.

Preliminary design

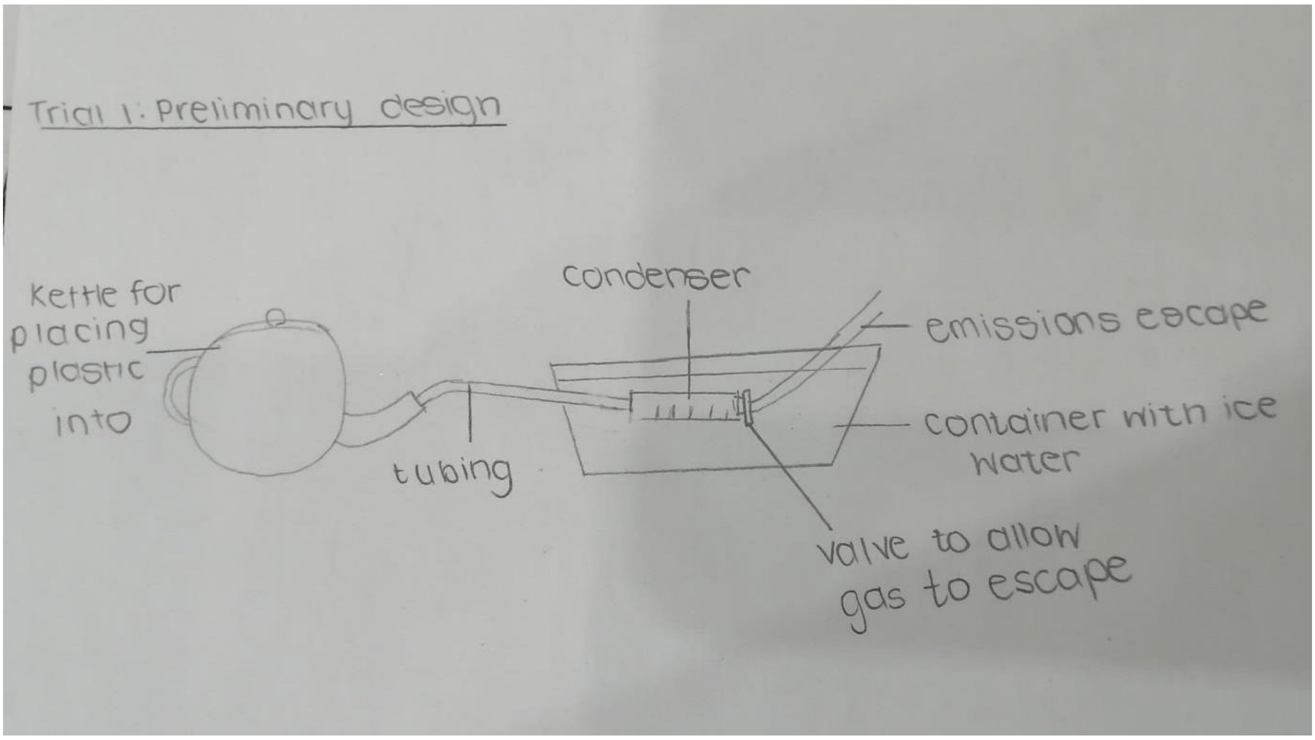


Figure 7: Trial 1 Preliminary Design of the experimental system

Construction method:

Step 1: Close the container and ensure there is a small orifice for the tube to connect to.

Step 2: Place one end of the tube into the kettle.

Step 3: Place the condenser on the other end of the tube.

Step 4: Place the condenser in a container of ice.

Step 5: Place another tube on the opposite end of the condenser for the waste gasses to come out of.

Step 6: Ensure the valve of the condenser is open so that the gas can travel through the tubes.

Figures 8 and 9 show the container with ice in which the condenser will be placed. In Figure 10, the kettle was connected to the condenser and the experimental set-up can be seen in Figure 11.

Figure 8: Connect the tubes

Figure 9: Ice is needed to cool the gas

Figure 10: Connect the kettle

Figure 11: Experimental system

<u>Safety measures:</u>

1. Ensure the container is properly closed.

2. Wear a gas mask, gloves, and safety goggles.

The safety measures that were taken are shown in Figure 12 and 13.

Figure 12: Safety equipment

Figure 13: Foil placed to decrease room for emissions

Experiment: Burning plastic on a gas stove

Step 1: Put the 50 grams of plastic inside the kettle and close it.

Step 2: Put the gas stove on.

Step 3: Keep a timer on and measure the temperature at every thirty seconds.

Step 4: The gas from the burning plastic moved through the tube and condensed into oil droplets.

Step 5: Measure the temperature of the plastic at this stage to see the temperature that the plastic melts.

Step 6: Measure the amount of plastic fuel that is produced and the time it took.

The plastic fuel that was produced and the plastic fuel burning are shown in Figure 14 and 15.

Figure 14: Fuel produced

Figure 15: Plastic fuel burning

Trial 2:

Trial 2 used the information gathered from Trial one to design the correct equipment needed and to improve the method of construction. A vessel was made from stainless steel to ensure there were no leakages. It was designed by the researcher to have an entry for the plastic to be placed into and an orifice for the gasses to escape through. Three fuels were used: 1. Natural gas, 2. Coal and 3. Plastic waste. There were three test runs for each fuel to ensure accuracy of results. Data was collected by measuring the amount of plastic fuel that was produced when plastic was burned by each of the fuels (Set A, Table 2). The temperature was measured against the time as the fuels burned the plastic (Set B, Table 2).

Preliminary Design

The preliminary design can be seen in Figures 16 and 17.

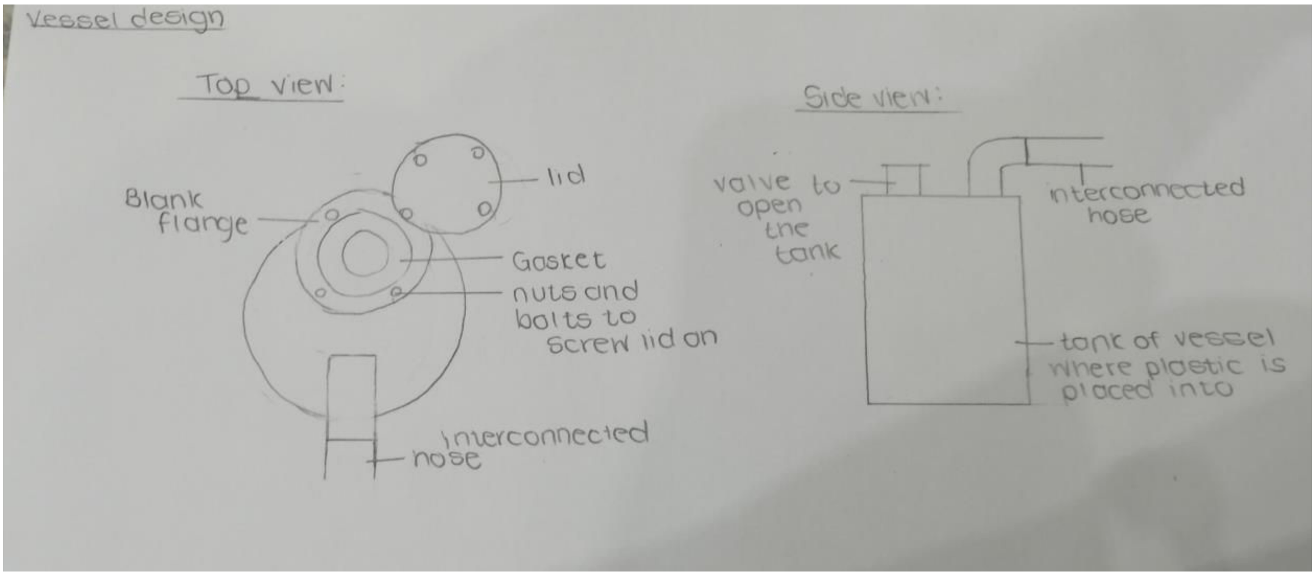


Figure 16: Vessel Design

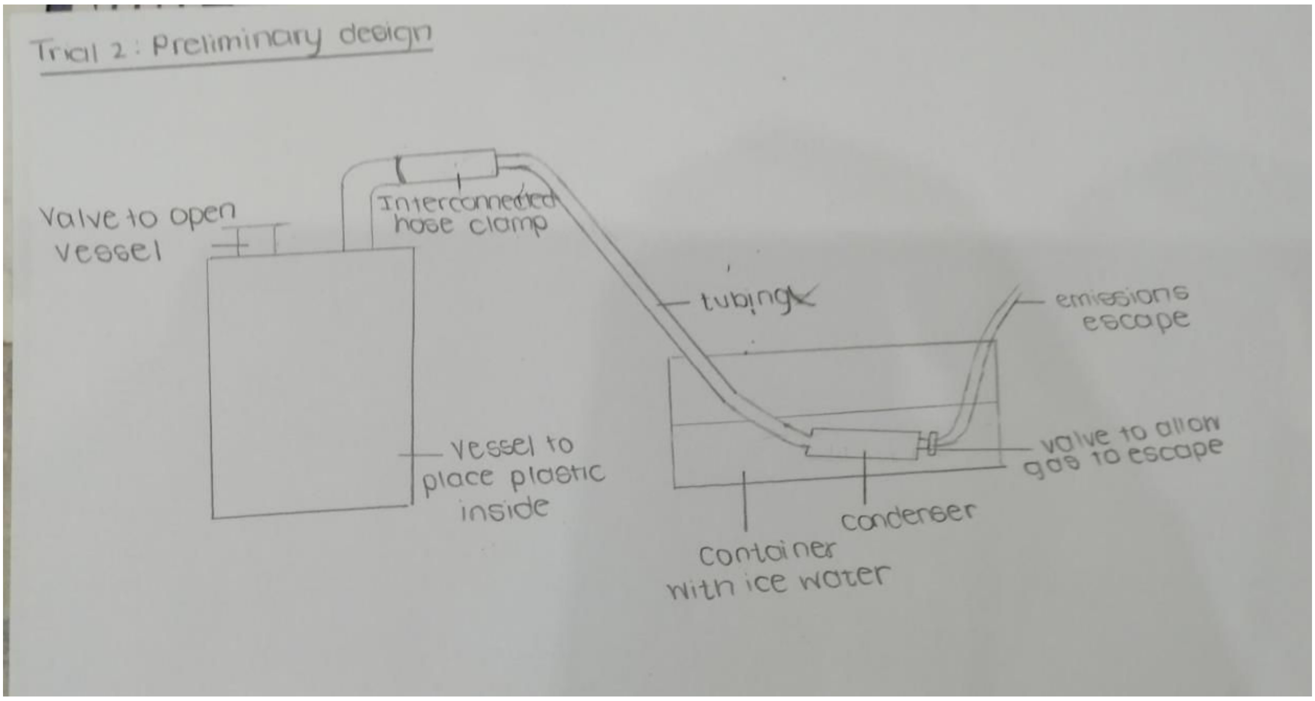


Figure 17: Trial 2 Preliminary Design of Experimental System

Construction method:

Step 1: The vessel should have two openings, one for the plastic to be placed into and one for the gas to escape from the vessel. An interconnecting hose was used to connect the vessel to the condenser. Tighten the interconnecting hose with clamps to prevent gas from escaping.

Step 2: Place one end of the tube onto the hose clamp.

Step 3: Place the condenser on the other end of the tube.

Step 4: Place the condenser in a container of ice.

Step 5: Place another tube on the opposite end of the condenser for the gas to escape the vessel from.

Step 6: Ensure the valve of the condenser is closed allowing the gas to flow through the pipes.

Figures 18 – 23 shows the Stainless-Steel Vessel and the set-up for Trial 2.

Figure 18: The vessel was built with two orifices.

Figure 19: The tube that the gas will flow through has a hose clamp attached to it.

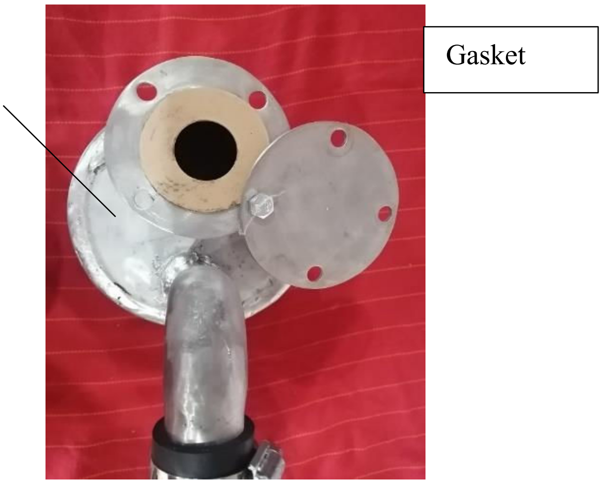


Figure 20: The gasket is used to stop the gas from escaping.

Figure 21: There is a blank flange that can be screwed and unscrewed to inject plastic.

Figure 22: Plastic placed into the vessel.

Figure 23: The experimental set-up.

Safety measures:

Safety measures should still be maintained to ensure that nature and the researchers are protected as there is fire and chemicals in the experiment. The safety measures are mentioned in Trial 1.

Experiment: Part 1- Burning plastic on a gas stove

Step 1: Put the plastic inside the vessel and close it.

Step 2: Put the gas stove on.

Step 3: Keep a timer on and measure the temperature at thirty second intervals.

Step 4: Observe when the gas from the burning plastic moved through the tube and condensed into droplets.

Step 5: Measure the temperature of the plastic to determine the temperature that the plastic melted at.

Step 6: Measure the amount of plastic fuel that is produced, and the time taken to produce it.

Figure 24: The vessel was placed on the gas stove.

Figure 25: The experiment was repeated three times using gas as a fuel.

Experiment: Part 2- Burning plastic using coal

The same procedure from part 1 is used, except the fuel used to burn the plastic is coal and not natural gas. This is shown in Figure 26 and 27.

Figure 26: The vessel was placed in coal.

Figure 27: The experiment was repeated three times using coal as a fuel.

Experiment: Part 3 – Burning plastic using plastic fuel

The same procedure from part 1 is used, except the fuel used to burn the plastic is plastic fuel and not natural gas. The fuel that was used and is being burned is shown in Figure 28 and Figure 29. Figures 30 and 31 show the test experimental set-up of the experimental system for the plastic fuel.

Figure 28: 90ml of the plastic fuel that was produced was burned.

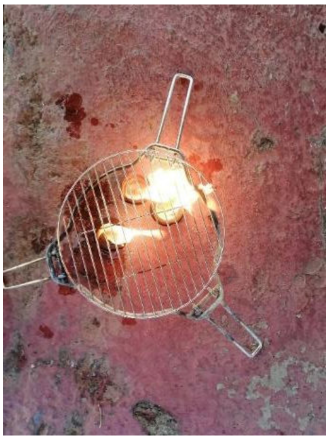


Figure 29: The plastic fuel was placed in three small pots and set alight.

Figure 30: The vessel was placed over the plastic fuel fire.

Figure 31: The experiment was repeated three times using plastic fuel as a fuel.

<u>Trial 3:</u>

The metal vessel that was constructed for trial 2 was still used in this trial. The distillation apparatus was changed. There was a new condenser added which consisted of a tube within a tube. Water flowed in the outer tube, and this surrounded the inner tube where the gas flows. This turns the gas into the plastic fuel. There is a tube at the bottom where the emissions can escape. The plastic fuel collects in a beaker. The emissions escape the room through the fuming cupboard. This provides for a safe investigation. The set-up can be seen in Figures 33 – 38.

Preliminary Design

The preliminary design for Trial 3 can be seen in Figure 30.

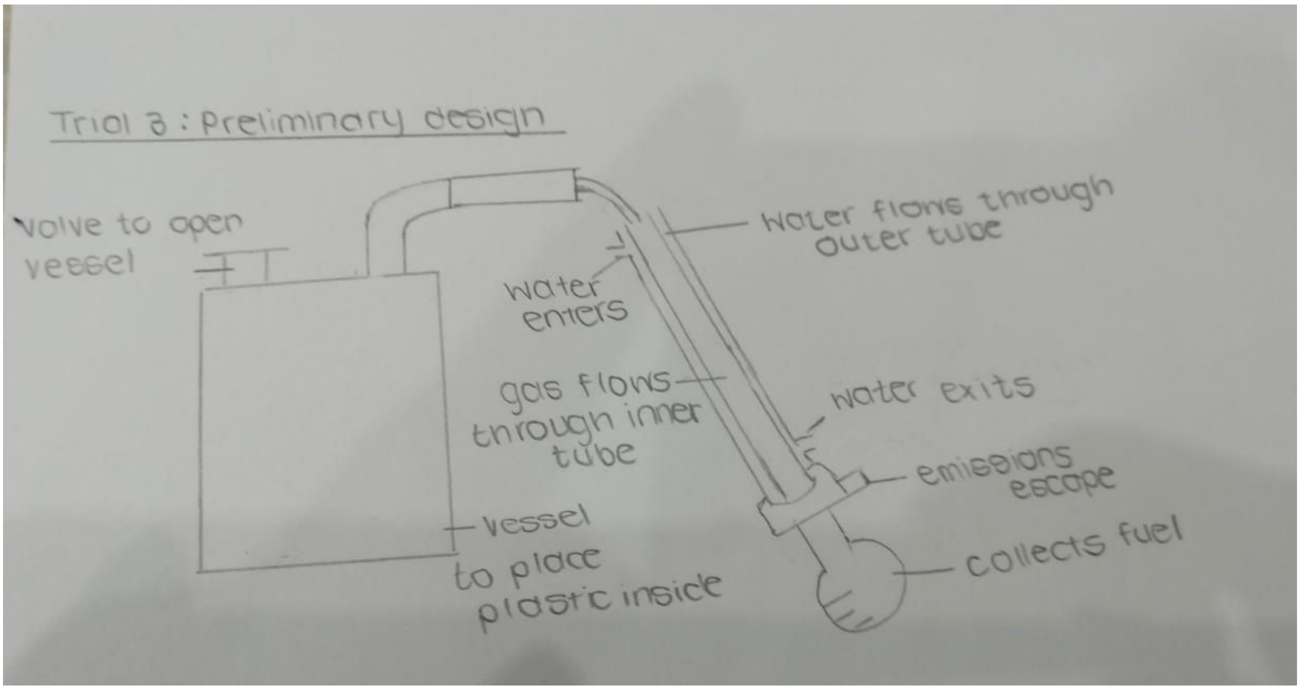


Figure 32: Trial 3 Preliminary Design of the experimental system

Construction method:

Step 1: The vessel should have two openings, one for the plastic to be placed into and one for the gas to escape from the vessel. An interconnecting hose was used to connect the vessel to the condenser. Tighten the interconnecting hose with clamps to prevent gas from escaping.

Step 2: Place one end of the tube onto the hose clamp.

Step 3: Place the condenser on the other end of the tube.

Step 4: Place two tubes on the condenser openings. This will be where the water flows through.

Step 5: Place a tube with two open sides and an open orifice on the opposite end of the condenser for the gas to escape the vessel from.

Step 6: The tube with the orifice should be attached to a beaker.

Figure 33: The fume cupboard allows the gas to escape the room.

Figure 34: The vessel was placed onto a gas stove, and the process was repeated for plastic fuel and coal.

Figure 35: The condenser has a tube where water passes over the inner tube.

Figure 36: Two pipes are placed onto the outer tube of the condenser to allow water through.

Figure 37: The system is placed into the fume cupboard.

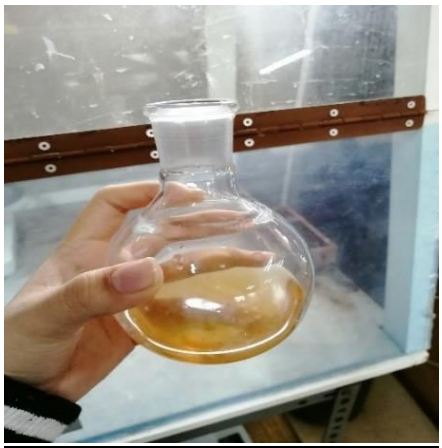


Figure 38: There is more plastic fuel collected as there is less gas escaping.

<u>Safety measures:</u>

Safety measures should still be maintained to ensure that the surrounding environment and the researchers are protected as there is fire and chemicals in the experiment. The safety measures are mentioned in Trial 1. There was a fume cupboard that was included in this trial. This made the investigation safe as the gas escaped the room and did not come into contact with any people.

The same procedure from Trial 2 Part 1 was used. This process is done for the coal, natural gas, and plastic fuel.

7.4 Additional Experimentation

The two waste products that have been identified throughout the experiments, are gas emissions and a solid carbon waste.

7.4.1 How to clean the gas emissions

The gas of high energy has been run through the system to be burned as an additional fuel. The heavy and dangerous particles will be removed. There will still be a small amount of gas left after it has been used as a fuel. This gas needs to be cleaned before it is released into the environment. The main gas emission that needs to be cleaned is carbon dioxide. This was done by adding aqueous ammonia into the gas. This forms a new compound which enters a solid state. This solid is able to combine with the other solid carbon waste.

Figure 39: Ammonium solution used to filter carbon dioxide

Figure 40: The system was improved

Figure 41: An improved condenser was installed

Figure 42: A larger beaker

Previously, the gas emissions had not been run through the system more than once as it was not seen as it was a small amount created, so it could be released into the environment. In this experiment the gas was run through the system three times as an additional energy source, as this was being tested in this experiment. 5 millimetres of aqueous ammonia was added to the gas after it was run through the system three times. This formed a solid after it mixed with the gas, this solid collected additionally to the solid produced from burning the plastic. The gas emissions were cleaned and are safe to release into the environment.

7.2.2 How to use the solid carbon waste

<u>**Test 1:**</u>

The solid plastic waste collected after the plastic is burned and the solid waste from the filtering of the emissions are mixed together. There were 4 different amounts of solid plastic waste added to 100g of asphalt mixture, namely 0g, 5g, 10g and 20g. Water was added to these mixtures, they were left to dry for 21 days. There were three containers of each value, so three mixtures of the 0g, three of the 5g and three of the 10g, and three of the 20g. This leaves 12 containers. Three different containers of each type was necessary to test the accuracy of the investigation. The drill was marked at 2cm and when the line could no longer be seen, it meant that 2cm was dug into asphalt mixture.

Figure 40: Asphalt mixture

Figure 41: Asphalt mixture with water and plastic waste

Figure 42: 3 containers of each value of plastic waste was prepared

Figure 43: Time taken to drill hole into asphalt was measured

Experiment process:

Step 1: Mix asphalt with water (100ml) and solid plastic waste

Step 2: Leave the mixture to dry for 21 days

Step 3: Measure the time taken for a drill to create a 2cm hole in the asphalt

Test 2:

There was four buckets prepared for test 2. There four were one for 0 mg of plastic waste added to asphalt, 5g added to asphalt, 10g of plastic waste added to asphalt and 20g of the solid plastic waste added to the asphalt. This was 100g of asphalt and 100ml of water which was mixed with these values of solid plastic waste and left to dry for 21 days. After they dried, there was 100ml of water poured over the dried asphalt mixture, this was left for half an hour. It was then poured out and tested for how long it would take for the drill to dig a 2 cm hole into the mixture. The water was used to stimulate how roads would be affected by rain wetting the asphalt.

Experiment process:

Step 1: Mix asphalt with water (100ml) and solid plastic waste

Step 2: Leave the mixture to dry for 21 days

Step 3: Pour 100ml of water over the dried asphalt and leave for half an hour

Step 4: Measure the time taken to drill a 2cm hole in the asphalt

Test 3:

This test had four containers of the asphalt mixtures prepares, one for 0mg of plastic waste added to the asphalt, one for 5g of the solid plastic waste added to the asphalt, one for 10g of the plastic waste added to the asphalt and one for 20g of the solid waste added to the asphalt. These values of solid plastic waste was added to 100g of asphalt and 100ml of water. This was mixed together and left for 21 days to dry. This was then hit with a hammer 50 times, this was to simulate the pressure that the roads are placed under by cars and trucks. This was then tested to see the time it took to drill 2cm into the asphalt.

Experiment process:

Step 1: Mix asphalt with water (100ml) and solid plastic waste

Step 2: Leave the mixture to dry for 21 days

Step 3: Hit the dried asphalt 50 times with a hammer

Step 4: Measure the time taken for a drill to create a 2cm hole in the asphalt

Figure 44: Water poured over dried mixture

Figure 45: Hammering the 20g asphalt mixture resulted in cracking

<u>Filling a pothole</u>

The solid plastic waste of 10g was added to 100g of asphalt and placed in a pothole. It was left to dry and is now part of the road. This was not tested and taken as results. It was extra asphalt and was utilised to improved the quality of the local road.

Figure 46: Solid carbon waste remaining after plastic is burned

Figure 47: Solid carbon waste and asphalt mixture poured over pothole.

Figure 48: Water needed to be poured over the asphalt mixture.

Figure 49: The mixture was compacted and left to dry.

All the by-products of the plastic burning process was taken care off, making it a safe and clean experiment.

8. Results

The results were taken over a period of two days. The first day was a trial. The results from Trial 1 were discarded due to the inefficiency of the set-up. The second attempt was with the updated construction and produced results (Trial 2). Three fuels were used and there were three tests run on each fuel for accuracy. The amount of plastic fuel that was produced was measured for each fuel's first test run (Set A, Table 2). The time that it took to produce the plastic fuel was measured against the temperature at that time (Part B, Table 2). The times that were used as a measurement (in seconds) were 0 to 300 in 30 second intervals. After five minutes the gas stopped being produced, which meant that recording data past that would not be of use. Trial 3 was a final construction which included better distillation apparatus and a fuming cupboard. This made the measurement of results more accurate and provided for a safer investigation.

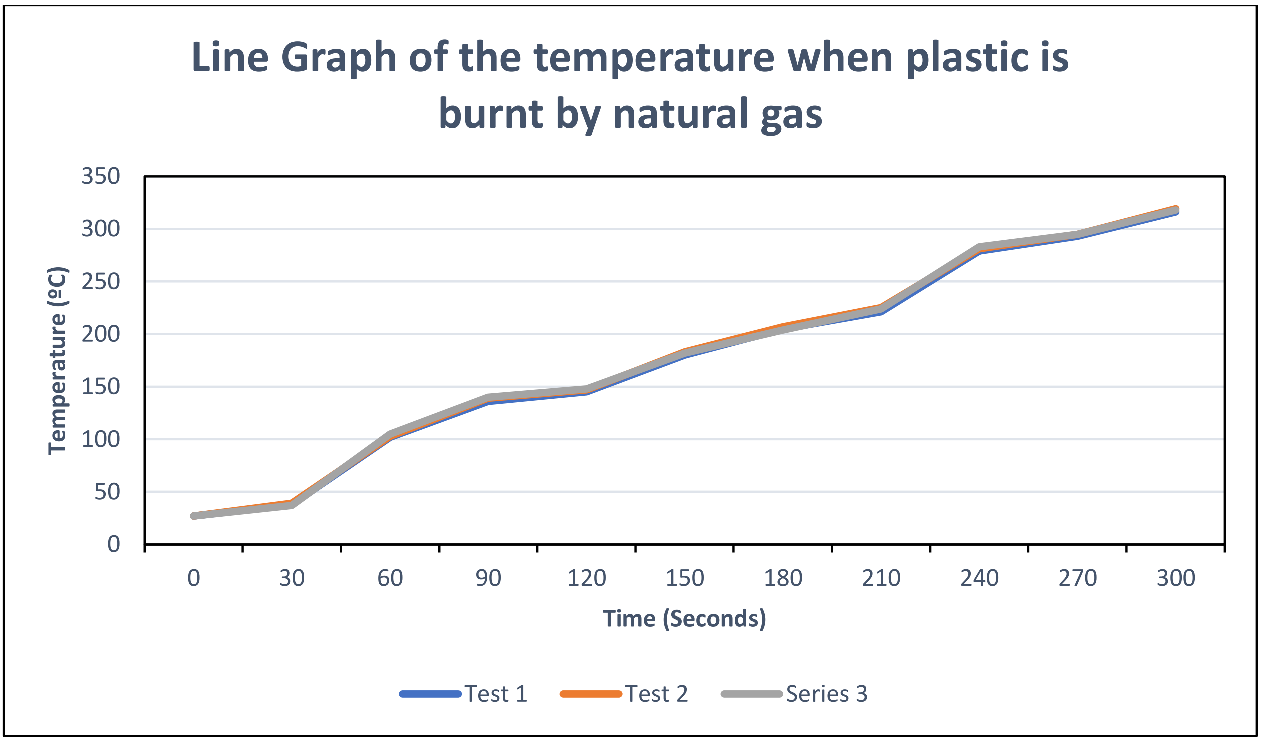
<u>The results from Trial 2 are shown below:</u>

It can be seen in Tables 4-7 and Graphs 1-7.

Natural Gas

Time (seconds)	Temperature (ºC): Test 1	Temperature (ºC): Test 2	Temperature (ºC): Test 3
0	27	27	27
30	38	39	37
60	102	103	105
90	136	139	140
120	145	147	148
150	180	183	182
180	205	207	204
210	221	225	224
240	279	281	283
270	293	295	295
300	316	319	318

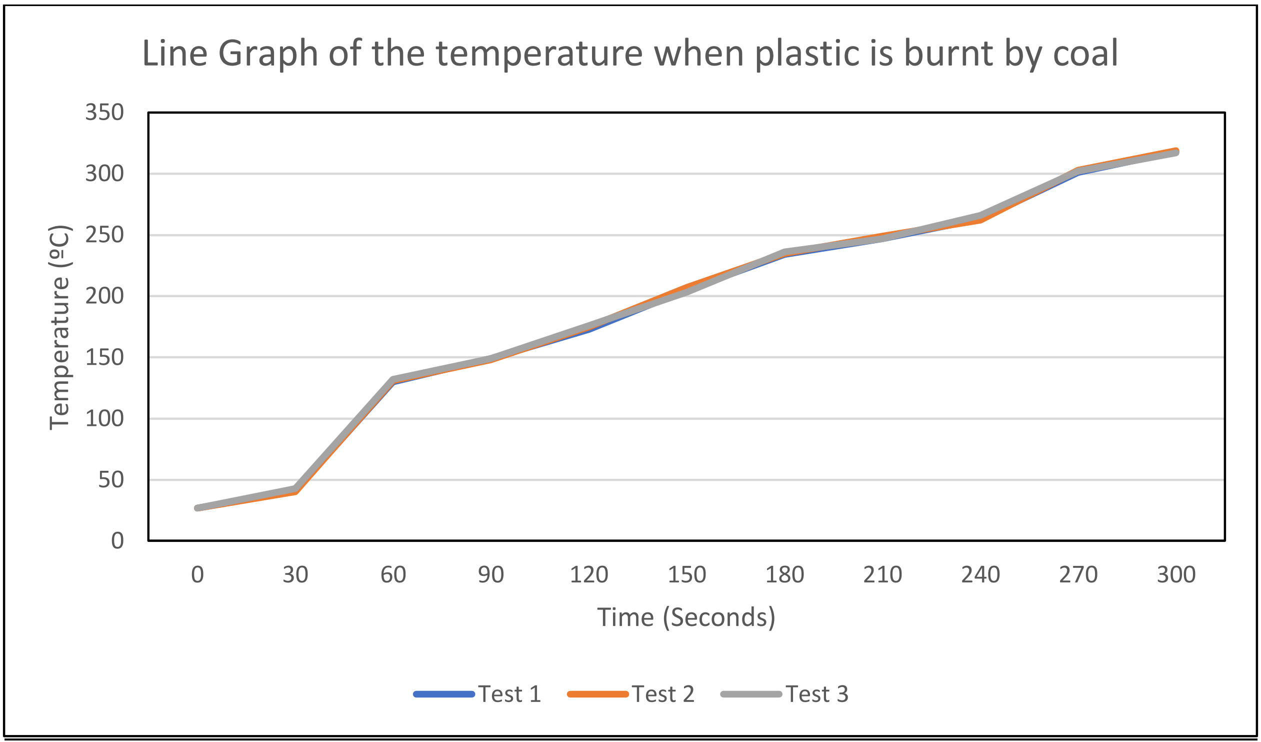
Table 4: Comparing the temperature measured in the three test runs against the set times when plastic is burned by natural gas.



Graph 1: Comparing the temperature measured in the three test runs against the set times when plastic is burned by natural gas.

Coal			
Time (seconds)	Temperature (ºC): Test 1	Temperature (ºC): Test 2	Temperature (ºC): Test 3
0	27	27	27
30	41	40	43
60	130	131	132
90	149	148	149
120	173	175	176
150	205	207	203
180	234	235	236
210	247	249	247
240	263	262	266
270	301	303	302
300	318	319	317

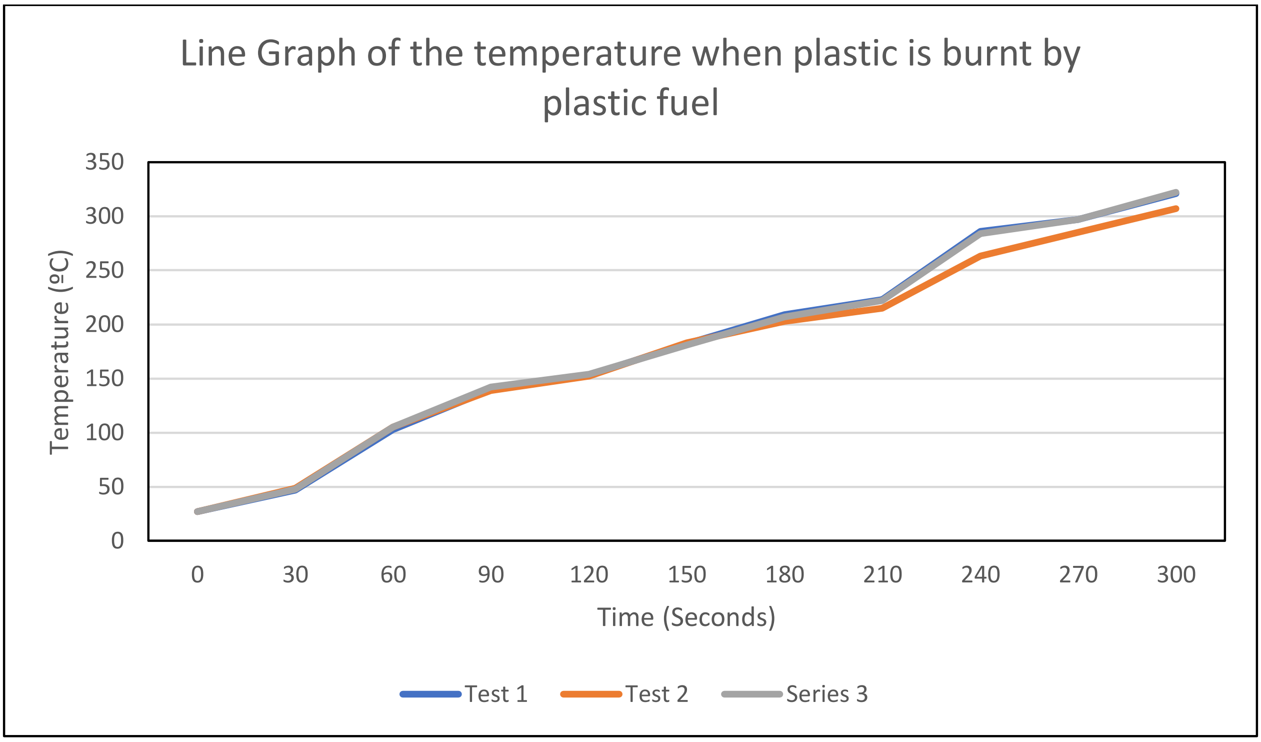
Table 5: Comparing the temperature measured in the three test runs against the set times when plastic is burned by coal.



Graph 2: Comparing the temperature measured in the three test runs against the set times when plastic is burned by coal.

Plastic Fuel			
Time (seconds)	Temperature (ºC): Test 1	Temperature (ºC): Test 2	Temperature (ºC): Test 3
0	27	27	27
30	47	49	48
60	103	105	105
90	140	139	142
120	153	152	154
150	182	183	181
180	209	203	207
210	223	215	222
240	286	263	284
270	297	285	297
300	321	307	322

Table 6: Comparing the temperature measured in the three test runs against the set times when plastic is burned by plastic fuel.



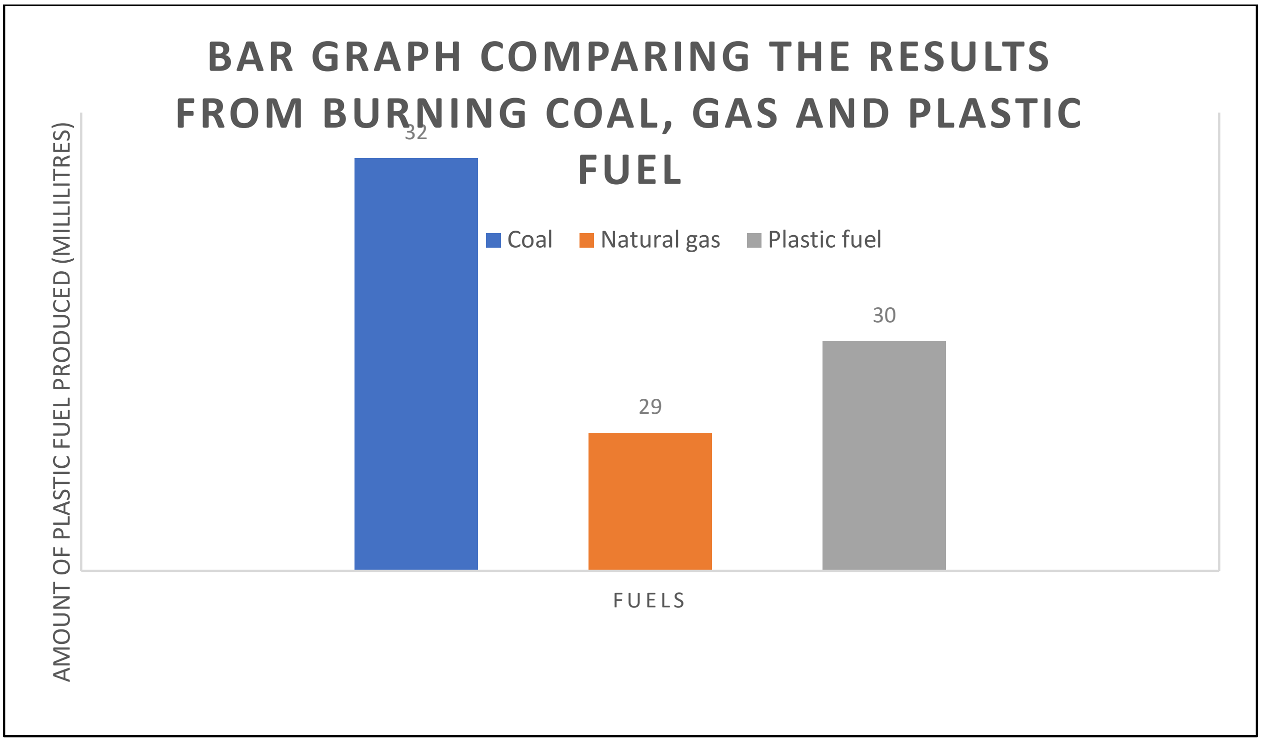
Graph 3: Comparing the temperature measured in the three test runs against the set times when plastic is burned by plastic fuel.

The results of the first test run of each of the three fuels were compared to each other. These results are the temperature and time at which the gas started being produced. The amount of plastic fuel that was produced is also compared.

	Coal	**Natural gas**	**Plastic fuel**
Temperature when gas was produced (ºC)	193	200	198
Time when gas was produced (seconds)	143	175	173
Amount of plastic fuel produced (millimetre)	32	29	30

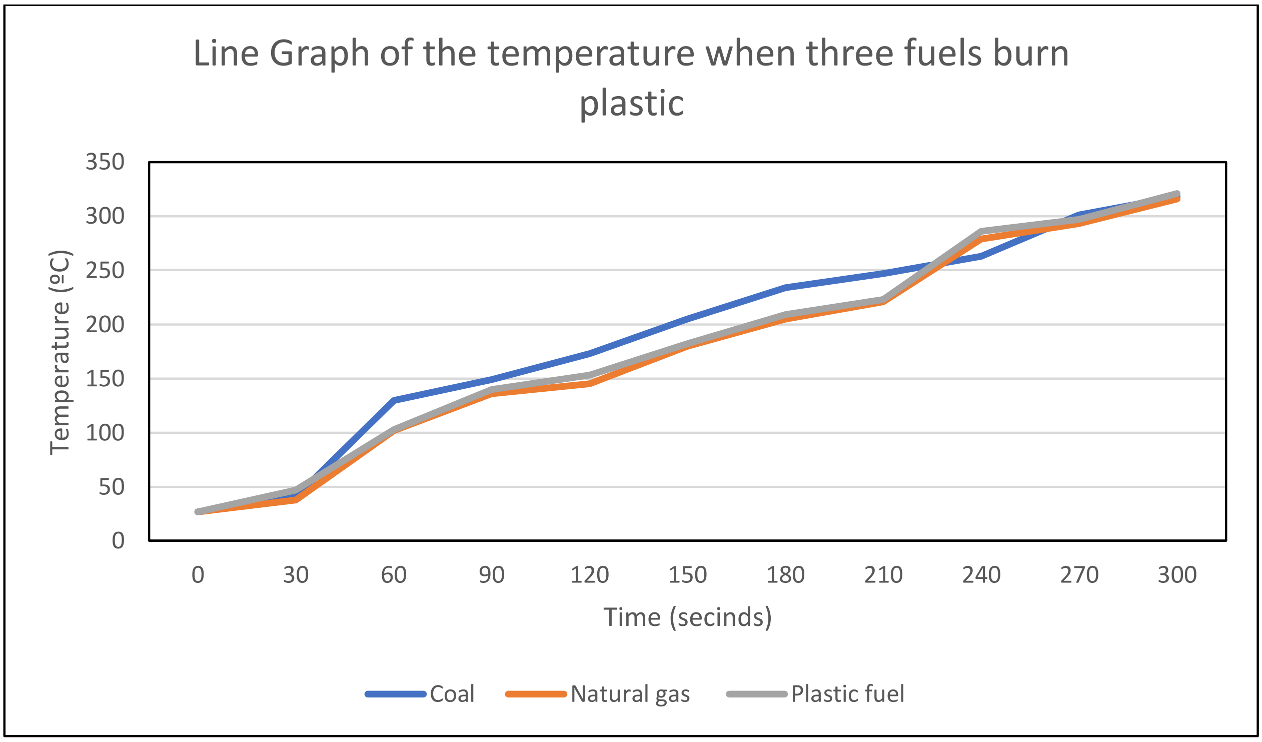
Table 7: Comparing the temperature, time and amount of plastic produced when plastic is burned by the three variables.

The amount of fuel that was produced by each of the first tests of the fuels is shown below.



Graph 4: Comparing the amount of plastic fuel produced by the first tests of each variable.

The temperature that was measured against the time that was taken to burn the plastic using the first tests of the different fuels is shown on the graph below.



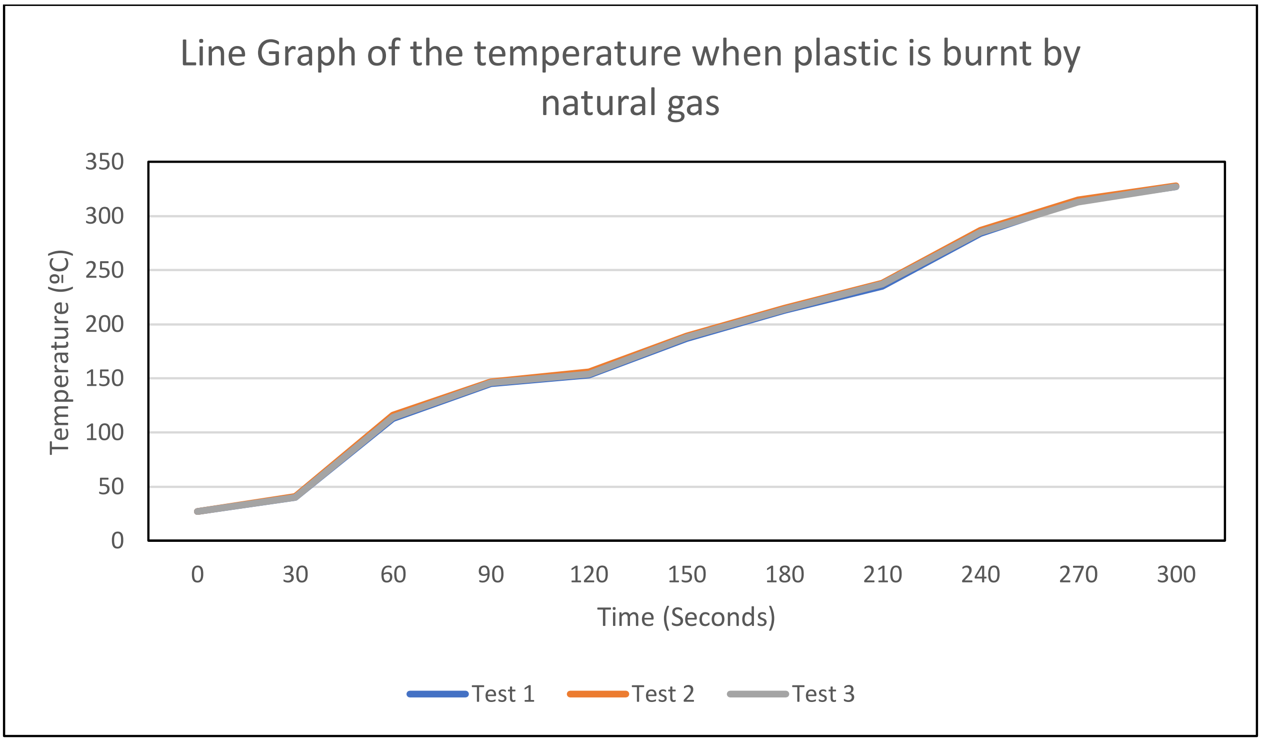
Graph 5: Comparing the temperature measured against time in the first tests of the three variables.

<u>The results from Trial 3 are shown below in Table 8 – 11 and Graph 6- 10:</u>

Natural Gas

Time (seconds)	Temperature (ºC): Test 1	Temperature (ºC): Test 2	Temperature (ºC): Test 3
0	27	27	27
30	40	41	40
60	113	116	114
90	145	147	146
120	153	156	154
150	187	189	188
180	213	215	214
210	235	238	237
240	284	287	285
270	314	315	313
300	327	328	327

Table 8: Comparing the temperature measured in the three test runs against the set times when plastic is burned by natural gas.

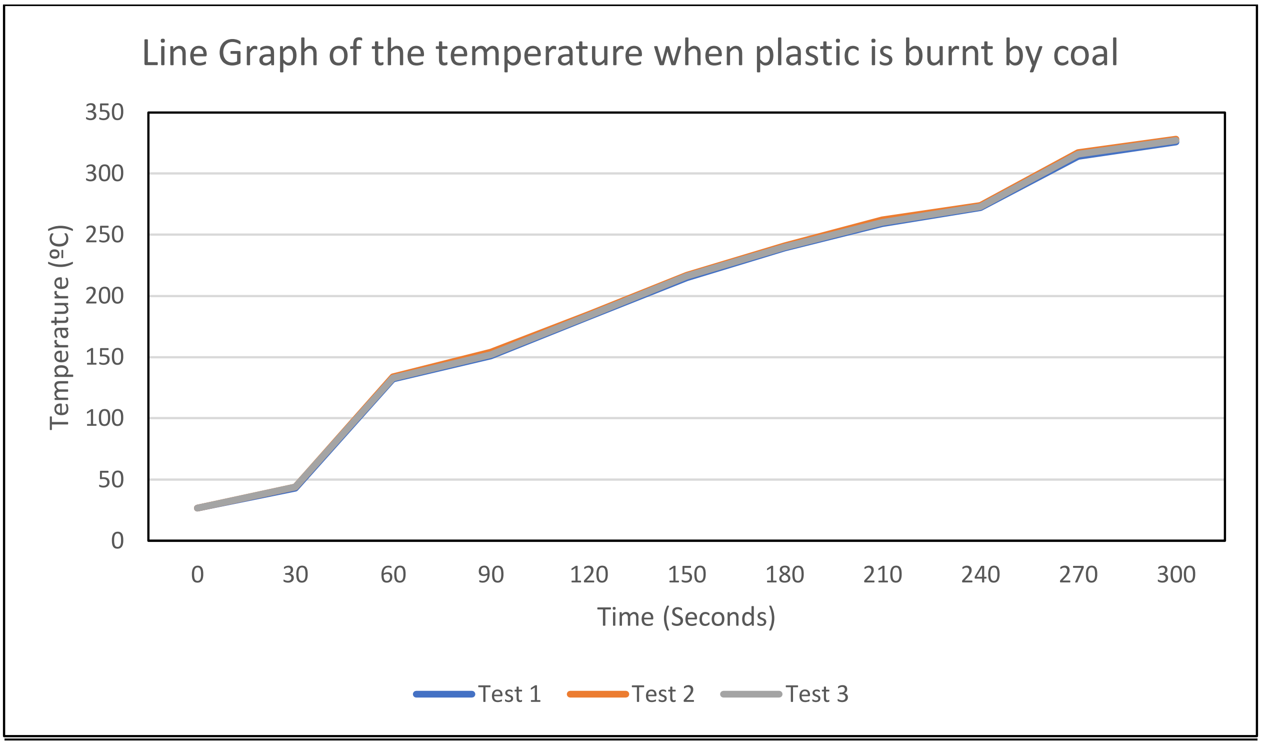


Graph 6: Comparing the temperature measured in the three test runs against the set times when plastic is burned by natural gas.

Coal			
Time (seconds)	Temperature (ºC): Test 1	Temperature (ºC): Test 2	Temperature (ºC): Test 3

0	27	27	27
30	43	44	44
60	132	134	133
90	151	154	152
120	183	185	184
150	215	217	216
180	239	241	240
210	259	262	260
240	272	274	273
270	314	317	316
300	326	328	327

Table 9: Comparing the temperature measured in the three test runs against the set times when plastic is burned by coal.

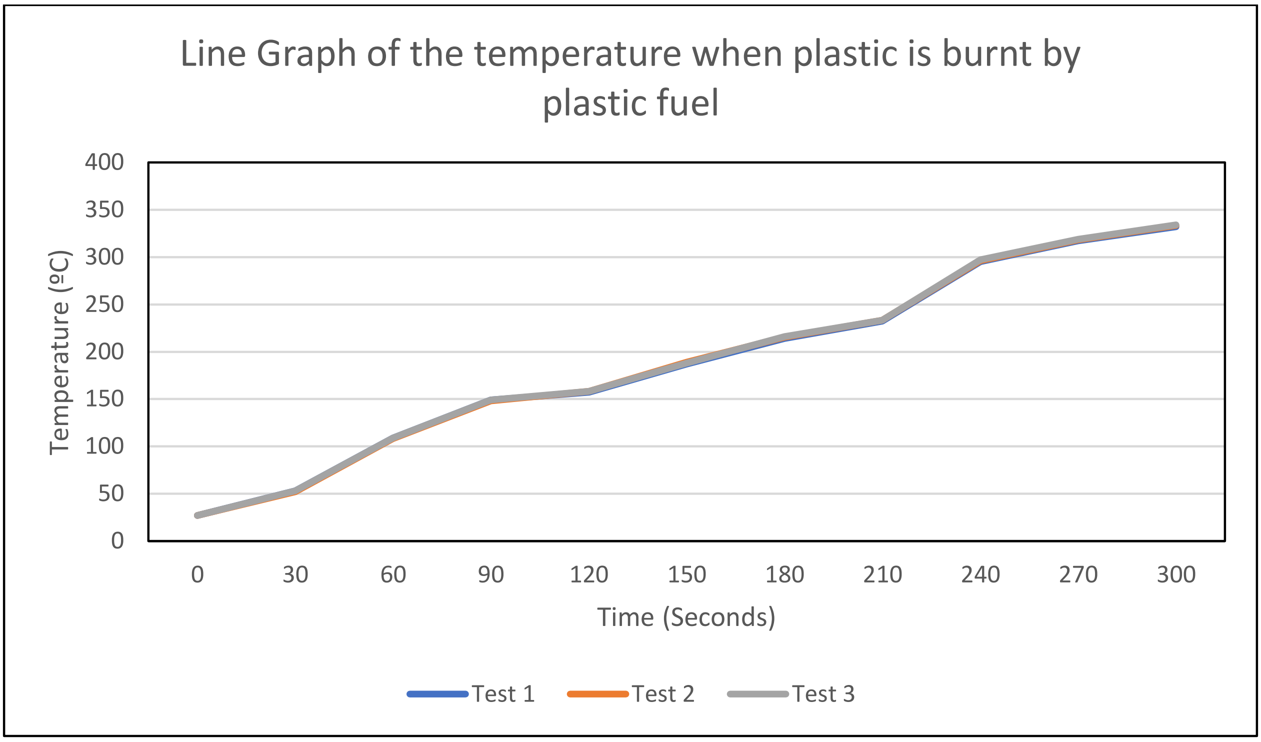


Graph 7: Comparing the temperature measured in the three test runs against the set times when plastic is burned by coal.

Plastic Fuel			
Time (seconds)	Temperature (ºC): Test 1	Temperature (ºC): Test 2	Temperature (ºC): Test 3
0	27	27	27

30	53	52	53
60	109	108	109
90	149	148	149
120	157	158	158
150	187	189	188
180	214	215	216
210	232	233	233
240	295	296	297
270	317	318	319
300	332	333	334

Table 10: Comparing the temperature measured in the three test runs against the set times when plastic is burned by plastic fuel.



Graph 8: Comparing the temperature measured in the three test runs against the set times when plastic is burned by plastic fuel.

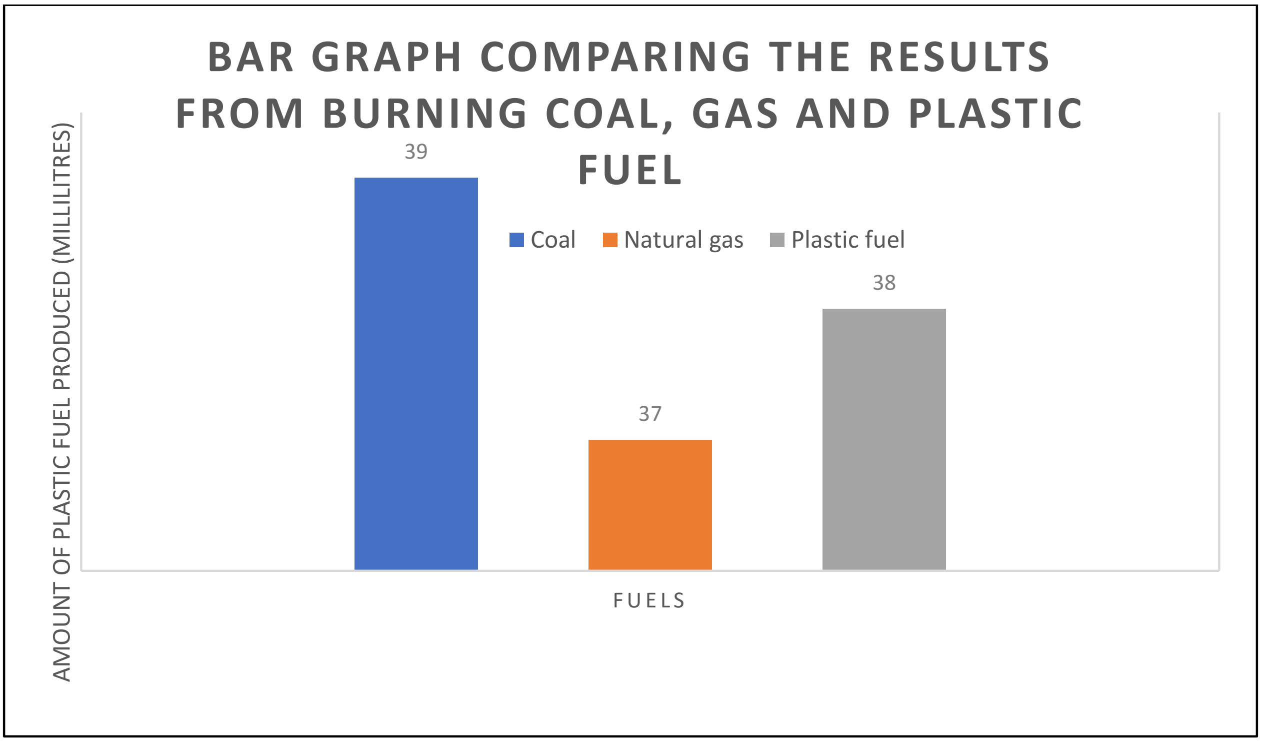
The results of the first tests of each of the three fuels were compared to each other. These results are the temperature and time at which the gas started being produced. The amount of plastic fuel that was produced is also compared.

	Coal	Natural gas	Plastic fuel

Temperature when gas was produced (ºC)	192	199	198
Time when gas was produced (seconds)	125	156	138
Amount of plastic fuel produced (millimetre)	39	37	38

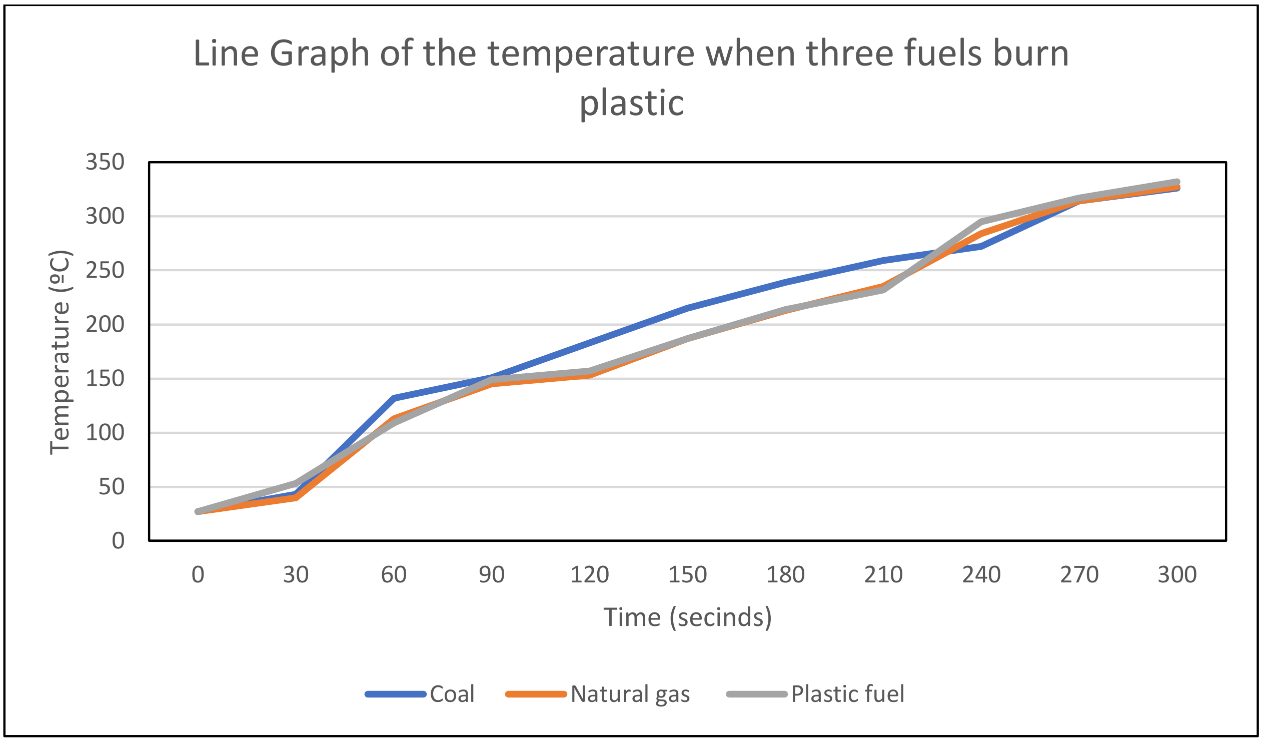
Table 11: Comparing the temperature, time and amount of plastic produced when plastic is burned by the three variables.

The amount of fuel produced by each of the first tests of the fuels is shown below.



Graph 9: Comparing the amount of plastic fuel produced by the first tests of each variable.

The temperature that was measured against the time that was taken to burn the plastic using the first tests of the different fuels is shown on the graph below.



Graph 10: Comparing the temperature measured against time in the first tests of the three variables.

8.1 Additional Results

Test 1:

The results from the investigation was taken for three containers of each amount of asphalt added, three for normal asphalt with 0grams of plastic waste, asphalt with 5grams of plastic waste and asphalt with 10grams plastic waste and 20grams plastic waste with asphalt. This was placed into a table. The table shows the time taken to dig 2cm into the asphalt for each of the different mixtures. This was after the mixtures were made and they were left for 21 days to dry.

Amount of plastic waste in asphalt	**Time taken (seconds) to dig 2cm hole: Container 1**	**Time taken (seconds) to dig 2cm hole: Container 2**	**Time taken (seconds) to dig 2cm hole: Container 3**
0 grams	37	38	37
5 grams	40	40	39
10 grams	43	44	42
20 grams	40	39	40

Table 12: Comparing the amount of plastic waste in the asphalt against the time it takes to drill a 2 cm hole into the asphalt for three different test runs

Test 2:

The results from the test was taken for the asphalt mixture of 100g of asphalt to 100ml of water with the different values of solid plastic waste. This was left to dry for 21 days. Rain was simulated by pouring 100ml of water over the dried mixture and leaving it for 30 minutes. The strength of the mixture and its ability to withstand these conditions were tested by measuring the time taken to drill a 2cm hole into the asphalt after water is poured out.

Amount of plastic waste in asphalt	**Time taken (seconds) to dig 2cm hole after water was left for 30min**
0 grams	37
5 grams	40
10 grams	43
20 grams	39

Table 13: Comparing the amount of plastic waste in the asphalt against the time it takes to drill a 2 cm hole into the asphalt after water was left on it for 30 minutes

Test 3:

The results from the test was taken for the asphalt mixture of 100g asphalt with 100ml of water and the different values of solid plastic waste. This was left for 21 days to dry and was hit with a hammer 50 times. This was done to simulate the pressure that the asphalt would experience as the road under the cars and trucks. The strength of the asphalt and its ability to withstand this pressure it would experience as a road is tested after it is hit 50 times, the time taken to drill a 2cm hole is measured.

Amount of plastic waste in asphalt	**Time taken (seconds) to dig 2cm hole it was hammered 50 times**
0 grams	37
5 grams	40
10 grams	43
20 grams	38

Table 14: Comparing the amount of plastic waste in the asphalt against the time it takes to drill a 2 cm hole into the asphalt after it was hammered 50 times

9. Discussion

Trial 1:

During Trial 1, only a gas stove was used to burn plastic. The plastic fuel produced was flammable. However, the kettle that was used, caught alight because of the gas collecting and condensing on the rim of the lid. There needed to be a vessel with less leakages and a tube which easily transfers the gas. The amount of fuel produced was very little to measure because of the leakages. The kettle could not be used as the experiment would not be safe. There also needed to be a larger container for condensing.

Trial 2:

The results from Trial 2 show that the plastic fuel burns at a similar rate when burned by plastic as compared to being burnt by coal and natural gas. This correlates with calorific values obtained by the Silesian University of Technology (Ryszard Wasilewks, 2013) The coal has a lower calorific value, but it was spread over a larger surface area and was in more direct contact than the other fuels. Therefore, the temperature of the vessel, when the coal was burnt, was higher than that of the other fuels.

The plastic fuel that was produced is 29, 32 and 30 millimetres (for natural gas, coal, and plastic fuel, respectively) as shown in Graph 4. This is just above 25 grams, which means that over 50% of the plastic turned into fuel. The results obtained from the experiment is also consistent with the Halisdemir studies under laboratory conditions (Neslihan Dogan, 2019). There is less fuel produced in this experiment as the container was not entirely sealed and this allowed gas to escape. There were also poor condensing conditions, and this could allow some of the gas from the plastic to escape through the tube with the dioxins and toxins.

The gas started being produced at about 200 degrees Celsius. This could be seen when the gas vapour came out of the pipe. The coal produced the plastic gas the earliest. This was due to the larger surface area that was covered by the flame. There was a lower temperature at which the gas started venting as the coal heated the vessel faster. The natural gas and the plastic fuel burnt at similar temperatures because of the calorific value. They heated up slower than the coal as the flame only heated the bottom of the vessel. The gas was produced 2°C lower when using the plastic fuel as compared to the natural gas. The coal covered a larger surface area. The natural gas only came out of the single flame from the gas stove.

The results from the three tests of the coal are similar to each other. The results from the three tests of the natural gas are similar to each other. The second test run of the plastic fuel is different from the first and third test run. This is due to the wind. The wind cooled down the vessel and changed the result of the test run.

Trial 3:

The condenser that was being used in Trial 2, allowed a large amount of gas to escape, which could have been turned into plastic fuel. This resulted in inefficient measurements. Improved distillation apparatus was added to Trial 3. A condenser with an upright tube was added, which was long enough to allow more gas to be condensed. The emissions could now escape through an open tube and get through the fume cupboard. This allows the harmful emissions to escape and prevents contact with any researchers.

The plastic fuel was collected, and it could be seen that the results were higher than the previous trials. There were no external factors, such as wind which disturbed the results. The amount of plastic fuel collected was more accurate and the temperatures were higher in Trial 3. The temperature at which the gas was produced was similar for Trial 3 and Trial 2. The time taken to reach this temperature was faster in Trial 3. The results from Trial 2 were similar to Trial 3, only differing in Trial 3 having a greater quantity of plastic fuel collected.

The plastic fuel that was produced is 37, 39 and 38 millimetres (for natural gas, coal, and plastic fuel, respectively) as shown in Graph 9. This is just above 35 grams, which means that over 70% of the plastic turned into fuel. The results obtained from the experiment is comparable with the Environmental and Eco-design of products and processes (Ismail I.M, 2016). These results support the hypothesis that plastics can be used as an alternative fuel source for incinerating plastic waste.

9.2 Additional results discussion

Test 1:

The results from the investigation show that the addition of solid plastic waste to asphalt increases the strength of the asphalt. This can be seen as the least time was taken to drill a hole into the mixture with 0 grams of plastic waste added, at 37, 38 and 37 seconds. The addition of 5 grams of plastic waste to the asphalt took 40,40 and 39seconds to drill a 2 cm hole into it. It took the longest to drill a 2 cm hole into the mixture with 10 grams of plastic waste, at 43,44 and 42 seconds. The time decreased to 40, 39 and 40 seconds to drill through the asphalt with 20 grams of plastic waste. This shows that 10% of the amount of asphalt lead to the best results in this investigation. This research coincides with Rajshahi University of Engineering & Technology which states that "research shows that 10-15% addition of plastic waste to the asphalt mix to construct road gives good results." (Md. Mahmud Sazzad, 2018).

Test 2:

The results from this investigation showed that the asphalt mixture with 0 grams, 5 grams and 10 grams of solid waste remained the same after water was left over it for 30min. This can be seen as it took the same amount of time to drill a 2cm hole into the asphalt when there was no water poured over the asphalt to simulate rain. This leaves the 0 grams at 37 seconds, which increases to 40 seconds for the 5 grams and the 10 grams remains at 43 seconds. The 20 grams of plastic waste added to the asphalt had decreased from the experiment where no water was added in test one. It decreased from 40 seconds to 39 seconds. This shows that it is a weaker mixture. The strongest mixture is the 10% addition of solid plastic waste to the asphalt.

Test 3:

The results from test three show that the asphalt mixture with 0 grams, 5 grams and 10 grams of solid waste remained the same after the dried asphalt was hammered 50 times. This can be seen as it took the same amount of time to drill a 2cm hole into the asphalt when it was not hammered in test 1 and when it was hammered in test 3 to simulate pressure experienced on the road. This left the 0 grams at 37 seconds, which increases to 40 seconds for the 5 grams and the 10 grams at 43 seconds. The 20 grams of plastic waste added to the asphalt had decreased from 40 seconds in test one to 38 seconds in test 3. This shows that it is a very weak mixture. Additionally, the 20 grams mixture cracked after being hit 50 times with a hammer. It is not strong enough to withstand the conditions of the road. The strongest mixture is the 10 gram mixture which did not change with the different conditions and was the strongest and longest to drill the hole into at 43 seconds.

10. Limitations and Error

A major limitation was that some household equipment was used in this experiment. This prevented the condenser from working to its full capacity and there were leakages in the vessel.

The tests were completed outside, therefore the wind played a factor in the temperature and heating of the vessel. The gas could not be concentrated inside the vessel as the wind was blowing it in different directions.

The leaks in the vessel meant that the vessel needed to be tightened continuously. There was a very small condenser that was used. This made it difficult for the gas to escape through the tube in the vessel. The vessel was made from stainless steel and was quite thick. The vessel could not conduct the heat as easily as the material was not the best conductor. Copper would be a good alternative.

The pipes for the vapour to travel along were very narrow, this made it difficult for them to escape the vessel. The vessel needed to be cleaned continuously as the vent pipe kept on becoming blocked, making it harder to collect gas. The flame was not in the same contact with the vessel when using the different fuels.

Burning in an open system caused emissions, which was not treated or tested in this investigation.

Additionally, some gas was allowed to escape when the system was open to add in the aqueous ammonia. In a closed system, there can be a hose that inserts this into the system.

11. Recommendations for future research

Future researchers can investigate using this plastic fuel on a larger scale in industries and place the plastic into an incinerator. Tests need to be done to see whether the plastic burns faster or creates more fuel when the plastic fuel is injected into the burner to make the plastic more flammable.

Testing can be done to see if the plastic will burn continuously or if there is a time interval when adding new plastic to wait for the plastic to heat up. By running the system continuously, you will see if fuel is produced faster or if more fuel is produced.

The condensers used should be bigger and of better-quality to see if more plastic fuel can be obtained from the burning process.

Plastic fuel can burn well, researchers can burn the plastic directly with the plastic fuel and not burn it through a vessel. This may produce better results.

The by-products of the burning process should be screened and filtered before letting them out into the atmosphere.

Additionally, the gas emissions can be screened to see what gases need to be cleaned additionally to the carbon dioxide. There should be an analysis of the solid waste formed and the chemical equation that occurs from the gas filtered to the solid that results. This should help to see what the solid waste product that results is and other possible uses for this solid waste.

12. Conclusion

The global problem of plastic waste can be solved by burning plastic through plastic fuel. The research proved that plastic fuel can be substituted for fossil fuel sources. The investigation also concluded that the temperature and time taken by plastic fuel to burn plastic correlates positively with that of coal and natural gas. It produced a similar amount of plastic fuel as these fuel sources. The hypothesis is accepted as the plastic fuel that was produced from burning plastic burns plastic similarly to coal and natural gas. This solves the problem of utilising expensive fuels in these plants, creating a self- sustaining system, while simultaneously limiting plastic pollution. **Additionally,** the cleaning of the gas emissions produces a solid waste. This waste mixes with the solid waste produced when plastic is burned. This solid waste can be added to asphalt to improve the strength of the asphalt and durability of roads. The waste products of the plastic burning process are used and the gases are clean to be released into the environment.

13. Acknowledgements

I would like to thank Mr. Shawn Siveraj (B.Sc. Eng. (Chemical)), who assisted me with the equipment, design, and facilities to carry out this experiment. I would also like to thank Miss Vallerine Singh, Miss Saskia Mahabeer, Professor Roshila Moodley and Mrs Pendie van Staden for their valuable inputs and contributions.

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【評語】100041

This study is to use the P.I.P. system to convert waste plastics into liquid fuel，which is entirely corresponding to the issues of sustainable development and circular economics. However，some suggestions and comments are raised for further study on this promising topic for the whole world，especially for the author.

1. The RIC code for the selection of waste plastics might not be fit for pyrolysis. For example，PVC with chlorine is recognized as producing toxic dioxin gas during pyrolysis. The condenser in the whole system is needed to be checked if the liquifying of dioxin can be achieved entirely to prevent the dangerous release into the environment.
2. How to control the reaction temperature of the pyrolysis process for converting the plastics？
3. Try to calculate the heat value of liquified fuel from the conversion of waste plastics. The suggestion is to use elemental analysis for the calculation of heat value.
4. The strengthening road is needed to use the standard process for verifying the strength，such as the impact test. And the test of weather resistance is also suggested.

5. Even the pyrolysis is successfully developed，the gasification process of hydrocarbon or plastics is widely discussed. The gasifying agents using CO2 or steam are recommended for this study，which is more beneficial for converting the waste into valuable fuels.