Micro-Controlled Recycling Machine that Converts Plastic Bottle Caps into Solid-State Oil Through Thermal Pyrolysis for Plastic Waste Reduction

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Abstract

This research aims to develop an alternative energy source which is cheaper and better than other sources. The study was done to achieve solutions to the increasing amount of plastics in the environment. The automated machine developed is capable of recycling plastic bottle caps to produce oil/wax through the process of pyrolysis using Microcontrollers or Arduino. For the method used for the study, descriptive type was implemented since it involves adequate and accurate interpretation of findings. It is also an appropriate method for the study since it aims to describe the present condition on plastic wastes that pollutes the environment. Then, based on the evaluation of the device based on its functionality (3.64), reliability (3.6) efficiency (3.54), maintainability (3.5) and portability (3.47), it got an overall average of 3.55, interpreted as "Good". It was also concluded that the device was eco-friendly since it converts plastic bottle caps into diesel fuel and user-friendly since it only needs to press a single button for the whole process due to automation. Finally, the device was recommended to have an automated centrifugal cleaning process, provides stronger motor and sharper blades for the motor and better condenser to produce better fuel.

Keywords: Pyrolysis, Automated, Microcontrollers, Arduino, Condenser,Centrifugal

1 Introduction

Developing alternative energy resources is the common study of researchers today. They tend to seek more sources of energy in a cheaper way, so as to achieve solutions to environmental problems that our society is currently facing (Privenko, 2017). Energy recovery from different wastes such as dry leaves, kitchen wastes, animal wastes, papers, etc. are some of the examples of which we can gather fossil energy like fuel. This waste to energy process contributes not only to our society but also it solves the environmental problems linked to waste management. Waste management is one of the best approaches in recycling waste materials that should be converted into something useful in lieu of being dumped anywhere and polluting the environment. One of the best examples is plastic; a plastic that has several benefits yet very abundant waste in our environment.

Plastics pose a major threat in our society and environment today, as it is the most abundant waste present in our environment. According to De Gruyter (2018), Plastic waste is a significant threat to the environment. A huge amount of plastic is produced and also dumped in the environment and continuously increasing every year. Of this, 50% is for disposable applications such as packaging and the majority of it has been thrown in the trash. As per sciencemag's study, the Philippines ranked 3rd in the list of highest contributors of plastic wastes dumped in the ocean (Williams et al. 2018). Plastics are flexible, durable and cost-efficient. Despite of the benefits that plastics offer, the harm that it causes has become a global problem and is affecting our environment and, on top of it all, the human life. As the uses of plastic increases, the effort of the government to collect and recycle these plastics decreases. As of 2015, only 9% of plastics have been recycled, 12% of it has been incinerated and the remaining 79% has been scattered elsewhere in the environment (Team Researchers of University of California, Santa Barbara, the University of Georgia, and the Sea Education Association). Marine pollution, land pollution, drainage blocking and air pollution are some of the problems that our environment is facing due to the abundance of plastic wastes.

Specifically, plastic bottle is one of the most abundant types of plastic. According to the research of The Guardian, every minute, millions of plastic bottles are bought around the world and the number will continuously increase up to 20% by 2021 (Taylor, 2017). This circumstance is said to create an environmental crisis as serious as climate change.

There are lots of methods for these plastic wastes to change into more useful resources. One of these methods is recycling. Creating new products such as, chairs, plastic bottles, and decorations are some of the examples. But what catches the researchers' attention is the possibility of these plastic wastes to be converted into energy. Plastics are typically made from petroleum and polyethylene terephthalate, which is highly recyclable. Due to the high heat of combustion of plastic, it is the most promising resource for oil production.

To reduce the plastic wastes and its negative effects, chemical recycling via pyrolysis is the best method to use. It is a process wherein the plastic wastes are heated at a high temperature with the catalyst in a closed chamber with the absence of oxygen. Unlike the process of incineration, catalytic pyrolysis does not generate some pollutants in the air, which causes environmental issues. In this study, the researchers aim to build a Micro-controlled Recycling Machine that Converts Plastic Bottle caps into Solid-State Oil through Thermal Pyrolysis for Plastic Waste Reduction. This study focuses on solid-state oil production from plastic bottle caps by thermal reforming processes. The researchers believe that this study will minimize the hazards caused by plastic wastes and it will also promote the environment protection. By conducting this study, the researchers hope that this will make a difference, no matter how small or big, that can help improve the quality of human life.

Materials and Methods/ Experimental Designs

PROJECT DESIGN - Descriptive Method is a fact-finding study that involves adequate and accurate interpretation of findings. It involves gathering of data that describes events and then organizes, tabulates, depicts, and describes data collection (Glass & Hopkins, 1984). It uses graphical representations such as graphs and charts to the understanding the data distribution. Descriptive research focuses on a present condition. Relatively, the method is appropriate to the study since it aims to describe the present condition on plastic wastes that pollutes our environment for the development and evaluation of the recycling machine.

PROJECT DEVELOPMENT - The project development was divided into different phases in order to accomplish the researchers' objective in an organized way. Each phase has a different focus than the other, and all is essential to the development of this project. The phases are Planning, Hardware Development, Software Development, Integration, Testing, and Evaluation.

Planning - In the planning phase, the researchers gathered information about the different approaches that can be done in order to turn plastic bottle caps into oil. The researchers picked one, which is the thermal pyrolysis, and focused on that approach. The researchers then brainstormed on how the design would be, and how the machine would be micro-controlled. The researchers also thought of the specifications that the machine would have and how they would achieve them. The researchers also identify the software and hardware requirements to be able to develop this project. Basically, this is the phase where the researchers specify and finalize the requirements, features, limitations, scope, and design of the machine.

Hardware Development - In hardware development, researchers have to develop not only the software part but also the hardware part of the design project. In hardware design, the following modules are required.

Figure 1 Heating Coil

A Heating Coil is a heating element made up of nichrome. It glows red and produces heat when electricity passes through it. Basically, it converts electricity into heat. This will be the one responsible of melting the plastic bottles in the reactor chamber.

Figure 2 Arduino Mega

An Arduino Mega is a micro-controller and it will be the one responsible of controlling the opening between the weighing storage and the reactor chamber, measuring and displaying of the load in the weighing storage to the TFT LCD. It is also responsible of displaying the remaining time before the current process is complete.

Figure 3 TFT-LCD

A TFT LCD or Thin-Film-Transistor Liquid-Crystal-Display is a kind of LCD that uses TFT technology to improve image quality. This LCD is also touchscreen. This screen will serve as the user interface of the machine. It would be responsible for displaying the temperature of the reactor chamber and the load of the temporary storage.

Figure 4 Copper Pipe

A Copper Pipe is a pipe made up of copper that has a variation of size. The researchers used a small copper pipe to direct the vapor from the reaction chamber into the condenser. It is connecting the chamber and the condenser.

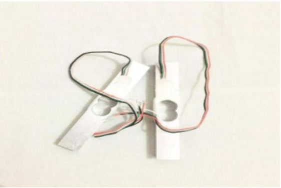

Figure 5 3kg Load Cell

A Load Cell is a transducer used to measure a load of a specific object. The researchers used a 3kg load cell, which would be responsible of measuring the load of the temporary storage and sending the data to the micro-controller. The load cell would be used with the HX-711, which is a kind of amplifier. It would be responsible of amplifying the measured load of the load cell.

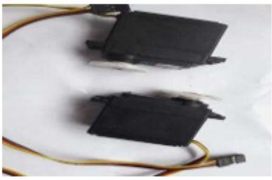

Figure 6 Servo Motor

A Servo Motor is a rotary actuator or linear actuator that allows for precise control of angular or linear position, velocity and acceleration. It would be micro-controlled and attached to the opening of the weighing storage, which will automatically open when the specified load is reached, transferring the plastic bottle caps to the reactor chamber.

Software Development - The next phase is the software development phase where the researchers develop the system of the machine. Since the machine only has minimal software features, the researchers used the Big Bang model. In the Big Bang model, most of the time was spent in determining the requirements, coding, and debugging. The process was repeated until the objective output has been achieved.

Requirements - The first part of the software development phase is the determination of requirements. This is the part where the functions of the software, and the interventions for each function are specified. In this part, the resources needed to develop the software were specified as well. The responsibilities of the software part of the machine must also be identified in this part. The software part of this project also has two parts: Micro controlling of hardware and the Graphic User Interface. The micro-controller will be collecting data from the load cell and temperature sensor, it would be controlling the servomotor, and it will be using the TFT LCD to display some data. The micro-controller must simultaneously perform those functions smoothly. In the GUI part, the micro-controller will be used to design the display in the TFT LCD. The display must be user- friendly and free of bugs. The display in the TFT LCD will contain the temperature and load watch.

Coding - The next part of the Big Bang Model for the software development phase is the coding. This is the part where the researchers program the micro-controller to enable it to fulfill its functions, which were specified in the requirements part. Since the display will be designed with the micro-controller as well, the designing stage is also included in this part. The program must be written in a manner where execution time is at minimal but still produces the expected output. The design in the TFT LCD must be organized and maximized. The touchscreen feature must also be accurate.

TFT Module - This module initializes the TFT-LCD for it to be programmed. Initialization of TFT-LCD includes setting the orientation of the display and the touch feature.

Servo Motor Motor Module - This module controls all the servo motors in the machine. The motors control the openings and switches of some parts of the machine. The code controls the motors either clockwise or counter-clockwise, depending on the current situation inside the machine.

Debugging - The last part of the Big Bang Model for the software development phase is debugging. This is the part where the researchers find and correct the logical and syntax errors of the program. This part is repeated until little to no bugs is present in the system. After this part, the system must run smoothly and must be almost bug-free.

Hardware and Software Integration - The integration phase is the phase where the software and hardware are combined to complete the project. The hardware and the software that were created beforehand were integrated perfectly to avoid malfunctioning. In this project, the micro-controller is connected to the parts it is controlling and is placed inside the machine where it is safe from disturbances.

Testing - The testing phase is conducted along with the integration phase. Every integration attempt, the machine is tested if it is functioning properly. If there are errors, troubleshooting and debugging is performed. If all the connections are correctly placed and the machine is still faulty, then there might be a faulty component that needs to be replaced. This part is repeated until the machine behaves as it is expected to behave. The machine will be tested using the Failure Modes and Effects Analysis (FMEA)

Block Diagram

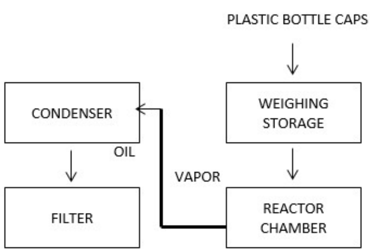

Figure 1 Block Diagram

Figure 1 The plastic bottle caps will be stored in the weighing storage. This weighing storage contains a load sensor that automatically sends the stored plastic bottles in the reactor chamber once it reached the weight of 500 grams. In the reactor chamber where there is an absence of oxygen, the plastic bottle caps are being heated through microwave heating with the use of coil. To monitor the temperature inside the chamber, temperature sensors are placed. This process will melt the plastics but will not burn. After it has melted, it will start to boil and evaporate. It will produce vapors that will go straight up to the cooling pipe. The vapors produced will be condensed into a liquid or solid wax and the vapors with shorter hydrocarbon lengths will remain as gas. The end of the cooling pipe is going through condenser containing water for the liquid forms of the fuel to float above the water, which will be captured.

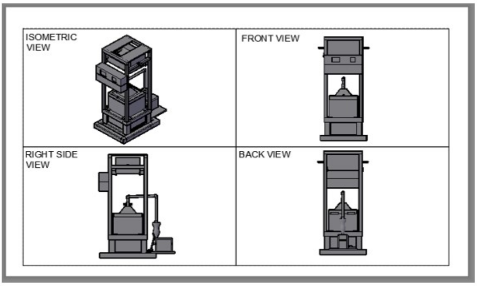

Figure 2 Hardware Structure

2 Results

Machine Testing

The researchers executed a machine testing. The test must be executed multiple times to ensure the consistency of the machine.

The machine test is the testing of the machine's time of completion per process. This can be done automatically or manually; The only thing that is important in this test is the time of completion per process. Table 4.2 shows the data gathered after multiple machine tests.

Table 1. Machine Testing Record

Testing No.	Input Load	Maximum Temperature	Time Started	Time Ended	Result
1	500g	350 °C	11:00 PM	3:40 PM	SUCCESS: Output is a bit waxy and flammable.
2	300g	350 °C	4:00 PM	7: 43 PM	SUCCESS: Output is similar with the first testing output but fewer.
3	500g	350 °C	2:20 PM	7:12 PM	SUCCESS: Output is the same as in the first testing.

Based on the table above, the given input loads with similar temperature of the device to perform pyrolysis successfully produced an output fuel though a bit waxy, it was able to satisfy the main purpose of the whole study.

Table 2 Functionality Evaluation Result

FUNCTIONALITY	MEAN	INTERPRETATION
1. The machine can produce solid-state oil from plastic bottles.	3.44	Fair
2. The machine functions better than the existing system.	2.92	Fair
3. The machine is easy to operate.	4.12	Good
4. The machine is safe to use.	4.04	Good
5. The machine's components are secured.	3.7	Good
OVERALL	3.64	Good

Table 2 shows that the respondents found the Functionality of the machine to be good with a rating of 3.64. The second criteria received the lowest rating of 2.92. It could be because the oil produced by the machine is solid.

Table 3 Reliability Evaluation Result

RELIABILITY	MEAN	INTERPRETATION
1. The machine can be used continuously without malfunctioning.	3.94	Good
2. The machine can recover from a malfunction.	3.08	Fair
3. The machine can function under any extreme weather.	4.16	Good
4. The machine performs consistently.	3.58	Good
5. The machine produces consistent output.	3.24	Fair
OVERALL	3.60	Good

Table 3 shows that the respondents found the Reliability of the machine to be good with a rating of 3.6. The second criteria received the lowest rating of 3.08. It could be because the components are hard to repair after a malfunction.

Table 4 Efficiency Evaluation Result

EFFICIENCY	MEAN	INTERPRETATION
1. The machine's components functions up to its maximum capability.	3.42	Fair
2. The machine does not waste any plastic.	4.02	Good
3. The machine's components react as soon as the input reaches them.	3.44	Fair
4. The machine functions the fastest possible way.	3.34	Fair
5. The machine's component's capacity exceeds the requirement.	3.48	Fair
OVERALL	3.54	Good

Table 4 shows that the respondents found the Efficiency of the machine to be good with a rating of 3.54. The fourth criteria received the lowest rating of 3.34. It could be because machine still functions slow compared to the expected speed.

Table 5 Maintainability Evaluation Result

MAINTAINABILITY	MEAN	INTERPRETATION
1. The machine can accept other inputs to test their corresponding output.	3.74	Good
2. The machine does not often require maintenance.	3.28	Fair
3. The machine can be used to test different possibilities with the components.	3.46	Good
4. The machine's components are positioned in a stable manner.	3.74	Good
5. The machine can easily be maintained if needed.	3.32	Fair
OVERALL	3.50	Good

Table 5 shows that the respondents found the Maintainability of the machine to be good with a rating of 3.55. The second criteria received the lowest rating of 3.28. It could be because the chamber often requires maintenance.

Table 6 Portability Evaluation Result

PORTABILITY	MEAN	INTERPRETATION
1. The machine's software can easily be transferred to other Arduino micro-controllers.	3.39	Fair
2. The machine is smaller than the existing system.	3.45	Fair
3. The machine's software can be easily installed on similar machines.	3.57	Good
OVERALL	3.47	Good

Table 6 shows that the respondents found the Portability of the machine to be good with a rating of 3.56. The first criteria received the lowest rating of 3.39. It could be because of the use of Arduino Mega, since most of studies only use Arduino Uno.

Table 7 The Weighted Mean of the Each of the Five Criteria

CRITERIA	MEAN	INTERPRETATION
FUNCTIONALITY	3.64	Good
RELIABILITY	3.60	Good
EFFICIENCY	3.54	Good
MAINTAINABILITY	3.50	Good
PORTABILITY	3.47	Good
OVERALL	3.55	Good

The design project received the highest rating of 3.64 in terms of Functionality and the lowest rating of 3.54 in terms of Efficiency, meaning that the device was a success in satisfying to solve the main problem but still needs for improvement.

3 Conclusion

Based on the aforementioned findings of the study, the researchers have concluded the following: The Micro-controlled Recycling Machine that Converts Plastic Bottles into Solid-State Oil can be designed in an eco-friendly and user-friendly way using the Descriptive method, and by considering the user-interface, process flow, utilization of components, and size. Next, the Micro-controlled Recycling Machine that Converts Plastic Bottles into Diesel can be developed by using the Big Bang Model.

Then the output can be tested by conducting FAME on the output by the Department of Energy and by testing it on a diesel machine. Also, the machine can be tested using FMEA by multiple testing. Lastly, the machine's level of acceptability on each criterion is the following:

Functionality - 3.64 Good
Reliability - 3.60 Good
Efficiency - 3.54 Good
Maintainability - 3.50 Good
Portability - 3.47 Good

Therefore the device was able to produce fuel from plastic bottle caps.

4 Recommendations

With the findings and conclusions given, the researchers hereby recommend the following for the improvement of the project:

- To automate the cleaning of the heater.
- To use a stronger motor and sharper blades for the shredder.
- To design a better power distributor for the servo motors.
- To design the condenser better so that the output is liquid.

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