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Technical Analysis: Generation of Electricity by Pyrolysis of Plastics in a Canadian Environment

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Abstract: The study takes motivation from provincial and national issues regarding waste management and electricity production in Canada. Most sources include previous research relating pyrolysis' applications in different parts of the world. The research included 2-3 weeks of extensive reading of previous research and understanding the theory relating polymers. Research has been conducted to understand why polymers have the properties that they do. Thorough analysis about the chemical reactions relating polymers on a small and large scale is conducted. More research was conducted relating to socio-economic conditions of Canada and Singapore for application purposes. Findings of the research point to an addition the Canadian government can uphold i.e., build more plastic pyrolysis plants in different regions for waste management. Our findings also suggest that the short term spending on such projects can yield long term benefits. This research is important because it will solve Canada's non-recyclable waste problems, it will help bring in a new source of electricity and it will help increase the budget of municipalities in the long run. This paper is not just informative on polymers, but also will help readers understand issues regarding Canadian waste management and propose possible solutions.
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Key words: Waste management, energy, electricity generation, power.

1. Introduction

Electricity generation is often a controversial topic in the first world. Most of the sources of electricity in the 21st century have some kind of a negative environmental footprint. For instance, fossil fuels are known for producing ridiculous amounts of greenhouse gasses that are hazardous for the environment. Canada needs to improve how it produces electricity [1]. According to statistics Canada, 61% of electricity—in the first 5 months of 2020—was produced from hydraulic turbines [1]. An average of 14% was produced from nuclear steam turbines and 18% was produced from burning fossil fuels. The rest 7% was produced from wind power, solar and other. Although the top 2 sources of electricity in Canada are relatively environmentally friendly and have little to no emissions, they still have their flaws. Hydropower has a reputation for causing havoc to marine life, and nuclear fission technology [2] is known to produce a lot of radioactive waste that takes thousands of years to decay if not decades. This being said, Canada does have a good reputation in recycling. However, there are still plastics out there that cannot be recycled and are hazardous to be reused. Most of the unrecyclable materials are sent to developing countries where they are either ignored or burned. This does directly harm the local population. These plastics can undergo pyrolysis rather than being dumped in a landfill to decompose for thousands of years.

This is why we consider pyrolysis of plastic to be the solution to Canada's waste management issues and the controversy surrounding electricity generation.

2. Combustion Theory

Pyrolysis of plastic waste is the process of the degradation of plastic waste in the presence of heat. The degradation process usually occurs between the temperatures of 350 °C to 900 °C in an environment without oxygen. The plastic breaks down into a fuel

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called "Char" and non-condensable gasses (organic and inorganic) such as, carbon monoxide, carbon dioxide, water, hydrogen gas, ethane, ethene, propane, propene, butane and butene, etc. The process of heating must be stabilized in order to produce relevant products.

Plastics are polymers that have high molar masses. An increase in molar mass is proportional to an increase in the stiffness of the plastic. However, the stiffness or softness also depends on the degree of crosslinking between polymers. The more the crosslinks, the more closely they are attached, therefore the plastic will be more stiff. The rigidity, density and degree of crosslinks of polymers depend on the number of dienes (double C-C bonds). This is important because it will help us understand a follow up property of plastics. Different plastics have different heat degrees at which they soften. Some plastics are capable of absorbing more heat than others. Thermoplastics have polymers that do not contain any crosslinks and will melt or soften when heated. Examples include polystyrene and polyethylene, etc. These plastics can be recycled to make new products. Some plastics, namely, "thermosetting plastics" will not soften at high temperatures because the strong covalent bonds are not overcome by heating. Some examples include: epoxy resin, phenol, formaldehyde.

The process of pyrolysis will take polymers with large molar masses and will break it down using either a catalyst, heat or hydrogen gas into a smaller chain of hydrocarbons (i.e., liquid fuel). This is in contrast to the Fischer-Tropsch (F-T) process that takes carbonaceous material and converts it into syngas (carbon monoxide gas and hydrogen gas). Attainable optimization technique will be used to conduct the pyrolysis process.

The plastics have also been divided into groups by the Society of Plastics Industry from which the following groups will be selected to produce fuel: HDPE (high density polyethylene), LDPE (low density polyethylene), PVC (polyvinyl chloride), PET (Polyethylene terephthalate), PP (polypropylene), PS (polystyrene). Co-pyrolysis of different plastics yields a wide range of products (making it difficult to separate). The different types of plastics will be taken to a size reduction process which will increase the surface area so more heat could have an influence on the polymers. The size reduction process will also help pack the materials within the reactor and will help mix solid particles more effectively [3, 4]. The reduced material will be introduced to the temperature range of 350 °C to 900 °C without oxygen within the reactor. The degradation process will take place in an environment well above atmospheric pressure. Once the heating process has begun, the reactor's pipes will be shut close so no vapor shall escape. Increasing the temperature will cause an increase in the vibrations which will cause the bonds holding the molecules to break apart into smaller molecules [3, 4]. The states of the molecules will change from solid to liquid to finally vapor. This is also when the char produced will be burned. After the completion of the process, the exit pipes (previously closed) will allow the vapor to flow where it will be sent to help in the production of electricity.

3. Generation of Electrical Power

The generation of electricity often involves turbines to convert mechanical energy to electrical energy. The types of turbines used generally include a gas turbine or a steam turbine. Gas turbines are often used in airplanes where the input air's kinetic energy and the combustion of the fuel contribute to generation of lift. Gas turbines can either be used in such an environment or can be ideal for producing electricity by burning oil and gas. Steam turbines on the other hand only use certain types of water. The heat from a reaction is absorbed by water molecules that heat up to become a steam, which help the turbine produce electricity. The main difference between a gas turbine and a steam turbine is that a gas turbine directly takes the pressurised mixture of gas and turns the turbine. However, the steam turbine involves the production of electricity indirectly and generally involves water. In some cases both can be used to improve the efficiency from [28% (industrial)-80% (experimental)] to above 50% (industrial). In this project, only steam turbines will be used as the gasses after pyrolysis as substances like soot can damage the turbine even after proper filtration [5, 6].

After the completion of the pyrolysis, the gasses mixture will be sent from the furnace/reactor. The reactor will be responsible for burning the gasses to produce energy and more gases. The gases leaving the furnace will be high in temperature and will cause the water in the superheater and economizer to evaporate. The steam parameters will increase as follows as it comes in indirect contact with the extremely hot toxic gasses: 370 °C/35 bar 440 °C/50-60 bar [6]. The pressure of the steam will stay constant whereas the temperature will vary [6]. The steam parameters will change again as the steam comes in indirect contact with the toxic gasses; with pressure being constant: 440 °C/50-60 bar 480 °C/50-60 bar. The kinetic energy of the particles of the vapor will be converted to mechanical energy in the turbine, which in turn will be converted to electrical energy. The steam will make its way down to the condensation station and the feed water tank, and ultimately will be boiled again as the process will repeat. The following procedure is based on IWMF (Integrated Waste Management Facility Singapore) that expects thermal efficiency to be about 28% [6, 7]. However, the efficiency can be improved to above 50% if gas turbines were also involved in the process.

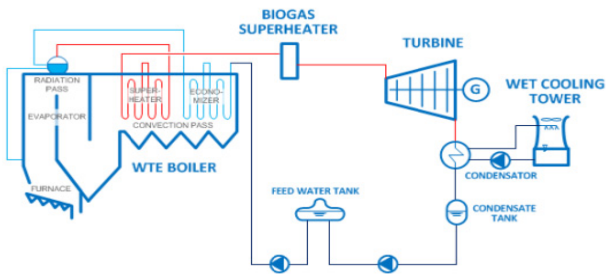

Fig. 1 Power plant designed by IWMF [6].

After the gases have done their job of heating up the water, the gasses will be forced into a Scrubber tower to filter out the toxic fumes before being released into the atmosphere [7, 8]. The electricity production can be seen in Fig. 1 which was designed by IWMF [6].

4. Valuation and Efficiency

From the years 2008 to 2016, the amount of disposed residential waste (in Ontario) has risen from 3.2 million metric tons to 3.7 million metric tons [9]. In Canada the number has jumped from 9.36 million to 10.2 million metric tons. And according to this trend the amount of disposed (not recycled) waste has a huge negative impact on not just local communities, but also the environment.

Three point eight percent (3.8%) of the residential waste that is disposed is plastic waste. And less than 11% of that waste is recycled. This means that more than 300,000 metric tons of waste was just disposed of in places like landfills.

In ideal experimental conditions, 100% of plastic waste should be converted to pyrolysis oil. However, often in experiments the efficiency is only a maximum of 80% i.e., 275,000 metric tons of plastics can be converted to fuel under experimental condition. This amount of plastics cannot go under pyrolysis under experimental conditions.

Although the experimental waste to fuel efficiency is low, this is not true for industry as IMWF as 90% of incinerable waste can be reduced. However, the efficiency of electricity generation is low (28%) this means that +75,600 metric tons (or 75,600,000 kg) of plastics can be converted to usable energy each year in Canada. If 1 kg of plastic can best produce 0.28 J of energy then the energy per year produced is 76 million joules.

5. Application

After the process of pryolosis char is also a byproduct in addition to the gasses. The char is a fuel that can be utilized and burned to produce energy as well. This is an important point because the following has not been taken into consideration during the production of electricity above.

Char can be extracted from the system which may or may not increase or reduce efficiency, but can be used as fuel for other applications i.e., oil lamps, vehicle fuels, etc.

6. Advantages and Improvements

Canada and the United States are often held accountable for shipping excess non-recyclable plastic waste to developing countries [10]. The main advantage of this system is that Canadians will have a new and effective way of getting rid of plastic and other non recyclable waste.

Canada and the U.S. have considered this process. However, vast application of this technology is not being done. Most municipalities and townships in Canada pay neighboring towns to deal with unrecyclable plastics. This can be avoided with the building of multiple waste management systems involving pyrolysis. One incineration plant can handle the waste of 7-8 towns while producing electricity that may satisfy a good fraction of their energy needs.

The opening of new pyrolysis plants will yield new jobs into the market. The jobs can range from unskilled to specialized. Various engineering, financial and computing jobs can be brought to the GTA. Opening of these plants will also mean more jobs for chemical engineers as they face a job crisis due to a decline in oil price. Very few chemical engineering jobs exist in this part of Canada which means a lot more jobs can be made for Canadians.

This technology promises to leave less waste materials that are less toxic than those produced from nuclear facilities.

There are a few suggested improvements necessary to make this system a "go to" for energy sources.

(1) Improve the efficiency: Current industrial data suggest a low efficiency of 28%. However, the reported efficiency in a smaller experimental stage is projected to be as high as 80%. This means that 52% of the efficiency is lost by having more energy to produce the 28%.

(2) Inconsistency: The amount of electricity will really depend on a daily basis as energy produced is based on the amount and type of plastic waste brought in the facility.

(3) Valuation: Is it really worth to spend billions on a project with considerable long-term benefits (new jobs, reduced carbon footprint, clean electricity)? But low short-term benefits?

7. Other Waste Management than Pyrolysis

While pyrolysis is a good alternative to leaving plastics in landfills, Canadians also produce a lot of bio-waste (food waste). The biodegradable waste is often also kept in landfills. This is not necessarily a bad thing, however, such immense amounts of waste is going to waste. We have the ability to convert biodegradable materials to energy via sludge incineration facilities.

8. Conclusion

Although the proposed pyrolysis plant has its advantages and flaws, overall it is a reasonable alternative to throwing plastics to landfills. Districts can and should consider this technology seriously as it may not just be good for the environment, but may also create skilled and unskilled jobs in small and large communities.

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