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Pyrolysis of plastic waste into fuel and other products

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Abstract

In this article, we propose, design and implement a sustainable process technology that converts plastic waste into useful products. The nature of the raw material for our process (plastic waste) make our proposed technology serve a dual purpose of not only taking care of the solid waste management problem, but also producing cheaper, safer and more easily accessible products for the rural communities. The envisaged outcomes of our research outputs are an improvement in the general lifestyle of our people living in less advantaged communities as well as an opportunity for employment creation of the local youth if our process is scaled up into an industrial plant.

Keywords: Pyrolysis, Waste plastics, Fuel, By-products,

1. Introduction

Domestic and Industrial solid waste collection and disposal systems in Botswana are not as efficient as those in other developing African countries. Specifically, the mode of disposal of domestic plastic waste in smaller cities and villages in Botswana is a major concern. In big cities, the current waste management systems mostly entail use of dumping sites and landfills, where the majority of the waste has been identified to be plastics from different sources such as clinical, industrial and domestic waste. Although the rate of reaction associated with the degradation process of plastic waste is said to be slow that it is kinetically approximated not to be taking place, it is however thermodynamically feasible. Some chemical engineering reaction based researchers have argued that plastics can be broken down by acidic leachates under certain harsh conditions of temperature and pressure to give products that are both deleterious and obnoxious to the environment and to the underground water sources which in some areas serve as drinking water for livestock, wildlife and even the rural folk.

The composition of different forms and types of plastics is such that it is made up of different elements, with some of them having an adverse effect on the environment upon pollution. Despite these stated numerous plastic waste issues, the Botswana Government has only responded to this societal challenge by implementing some policies and inviting some NGOs and private companies on-board in assisting to combat this waste situation. But this approach has only been useful mostly in urban areas while no progress has been reported in villages like Palapye and smaller towns like Serowe. In these parts of the country, plastic waste will continue to increase with negative implications on the local economies and environment.

In this research article, we focus on designing and implementing a sustainable process that uses the plastic waste as its raw material in producing useful chemical products.

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We will demonstrate the feasibility of our process by first producing a measureable quantity of liquid fuel in the form of paraffin. Our technology will not only solve the plastic waste disposal problems and reduce landfill challenges, but will also produce products that are of economic value to the rural populace thereby improving their livelihood. We will also use the attainable region optimization technique to improve the efficiency of our process.

2. Theoretical background

2.1 The pyrolysis process

Traditionally, the production of liquid fuels, high and low molecular chain hydrocarbons (organic chemicals) as well as energy, has relied heavily on the gasification of coal, distillation of crude oil and hydro-power. As our natural resources have become depleted, and continue to do so due to the exponential growth of world population, the need to look elsewhere for sources of raw materials and alternative processes is imperative. The pyrolysis method of synthesizing useful products uses techniques that are the opposite of the Fischer-Tropsh (F-T) process. In the F-T process, carbonaceous material e.g. coal, is combusted in order to give syngas ($CO + H_2$). The syngas is then synthesized into targeted higher molecular chain hydrocarbons e.g. petrol, diesel and paraffin. The pyrolysis process starts with higher molecular chain hydrocarbons (plastic), then break it down (cracking) using either heat, a catalyst or hydro-energy into targeted smaller chain hydro-carbons e.g. liquid fuels.

2.2 The Attainable Region Approach.

In this article, we will apply the Attainable Region (AR) optimization technique to optimize the objective function by way of manipulating the input variables to result in maximum process outputs. The AR method is a modern day geometric optimization technique that has been applied successfully in the different disciplines of chemical engineering. This approach owes its origins to the field of chemical reaction engineering where Hildebrandt and Glasser (1990) tested it in choosing optimal reactor configurations. Over the years, different researchers have used this optimization method on their laboratory scale data with the aim of either minimizing an experimental manipulated variable or maximizing an associated process variable. Since one of the objectives of operating any process is to make profit, the AR technique assists in this regard by way of specifying optimal experimental parameters that will result in either a maximum or minimum condition of the objective function. The greatest advantage of the AR method is its versatility. The versatility of the approach lies in that it is generic across the field of chemical engineering and a researcher can apply this technique on any process parameter of choice. Smith and Malone (1997) also applied the technique in organic industrial chemistry where they optimized the molecular weights, monomer conversions and residence time in isothermal polymerization systems. In 1998, McGregor et al. went on to use the geometric ideas of the AR method in process synthesis in which they optimized a reactor-separator-recycle system. Godorr et al. (1999) extended the application of the technique in selecting optimal control and operating policies to situations where the rate vector depends on a control parameter. In the year 2000, Book and Challagulla used the technique in order to obtain

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optimal design and operating conditions for the adiabatic oxidation of sulfur dioxide to sulfur trioxide. Nicol et al. (2001) applied the technique in order to find an optimum process design for an exothermic reversible reaction system where provision was made for an external heating and cooling source. Over the years, the technique has been further modified and employed in various fields of chemical.

3. Experimental procedure

Group plastics into their seven classification categories using plastic numbers (low density polyethylene, polypropylene, polystyrene etc.), this classification makes it easy to separate the fuel into different elements unlike when different types of plastics are used. The different plastic types are then taken through a process of size reduction to increase the surface area for heat to act on them. Size reduction also enhances packing within the reactor. The reduced material is introduced into the reactor for heating under a certain pressure and temperature, initially the opening in the reactor leading to the delivery pipe is closed so that no vapour should escape until a certain period of time. The molecular vibrations are directly proportional to temperature therefore at higher temperatures the molecular vibrations are increased. The increase in molecular vibrations causes the bonds holding the molecules to break into smaller molecules (solid to liquid then vapour state). After a period of time succeeding the start of the reverse polymerisation process, the pipe is open to allow the flow of vapour through to the condenser where it is condensed to liquid and collected. The analysis of the condensate for chemical compositions is then carried out in either gas chromatography or liquid mass chromatography. Interpretation and analysis is made on the results to know the elements that are in high quantities and make a background research on them. The last step is to extract the elements through separation processes that are suitable for each molecule or element.

4. Results and discussion

Structural analysis of the results from pyrolysis is important since it helps in understanding of the results so that better ways of optimization can be identified with ease. The documents attached with this article shows the gas chromatography pyrolysis results for the sample which indicates about two hundred and thirty nine (239) different components that where present in the sample. The high number of components could have resulted from the fact that different types of plastics where put into the reactor at the same time. The other reason for the high number of components could have been because the sample was heated to higher temperatures, high temperatures enhance the bond breaking in compounds therefore favouring the formation of more of the smaller components. High temperatures also ensure that more gaseous components are formed than liquid components. The large number of components made the analysis of the results much difficult, more time is neded to analyse the whole batch of sample so as a result wasting more time, resources. Ways of reducing the number of components should be implemented to make analysis more easy and efficient. The mass spectra that also include the retention times of the different components is shown also below. The fuel obtained can be used as a multifuel (diesel and gasoline engines), the fact that it can work on both the diesel and gasoline engines have not been verified through tests in

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those particular engines. The type of plastic used matters a lot in the type of fuel that can be obtained because literature has shown that if polyethylene (all kinds of flexible non break plastics) is used, the liquid fuel that solidifies as it cools into paraffin will be obtained. If polypropylene is used no paraffin will be formed but only liquid fuel will be obtained. This shows that it should be considered very well on which plastics to be used depending on the desired product output.

169	PR1:4	1,2-Di(prop-2-ynyl)cyclohexane	14274083
244	PR1:4	Cyclopentanecarboxylic acid, 2-amino-, cis-	3738403
76	PR1:4	Decane, 2,2,3-trimethyl-	7823160
203	1	2-Octene, 2-methyl-6-methylene-	12541919
274	PR1:4	Oxalic acid, hexyl octadecyl ester	11877995
32	PR1:4	Dodecylcyclohexane	915348
113	PR1:4	2-Heptyne-4-one	11015356
27	PR1:4	1-Octyn-3-ol, 3-methyl-	837606
37	PR1:4	Cyclobutene, 3,3-dimethyl-	26120068
213	PR1:4	7-Heptadecyne, 17-chloro-	6506185
38	PR1:4	Cyanic acid, 2-methylpropyl ester	4255647
171	PR1:4	Fumaric acid, 3-phenylpropyl tridec-2-yn-1-yl ester	2462827
30	PR1:4	4-t-Butylcyclohexylamine	903240
153	PR1:4	4-Benzoyloxy-1-morpholinocyclohexene	3556517
47	PR1:4	2-Butyn-1-ol	1268880
70	PR1:4	Spiro[2.5]octane	6204544
114	PR1:4	2-Propenoic acid, 2-methyl-, oxiranylmethyl ester	23644763
231	PR1:4	Cyclohexane, 1-bromo-2-methyl-	7511464
178	PR1:4	Glycine, furfuryl ester	18481423
5	PR1:4	2-Propenoic acid, oxiranylmethyl ester	7897995
191	PR1:4	2,7-Octadiene-1,6-diol, 2,6-dimethyl-, (E)-	5914992
192	PR1:4	2-Pentene, 4-bromo-	2234377
44	PR1:4	2-Butanone, 1-(2-furanyl)-3-methyl-	4524799

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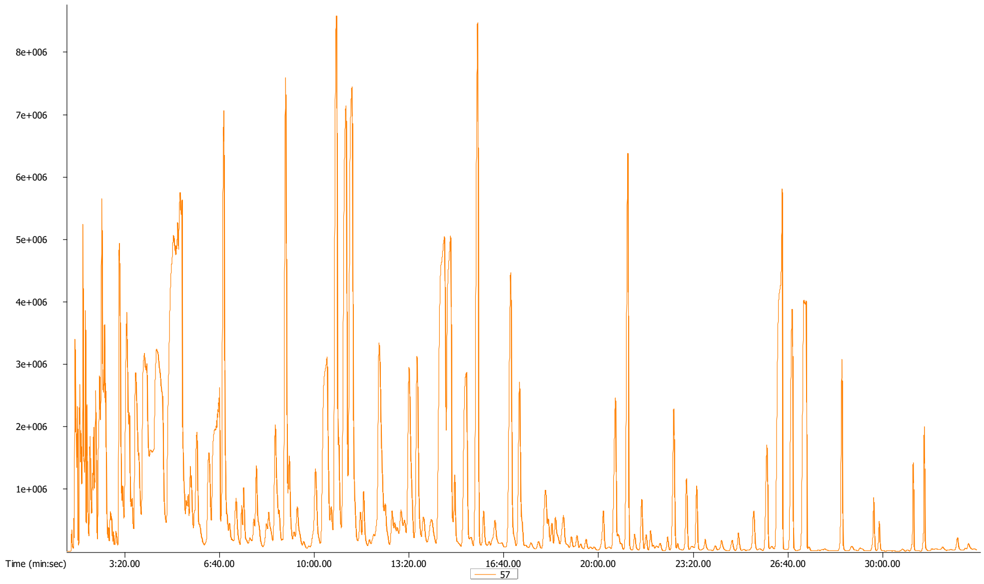

Figure 1:GC PROFILING DATA

Peak #	Sample	Area %	Name	Area	Group	R.T. (min:sec)	Weight	Similarity	UniqueMass	S/N
218	PR1:4	5.9689	Undecane	471030499	>0.08%	15:45.10	156	873	57	171521
95	PR1:4	5.9301	Ethylbenzene	467973040	>0.08%	5:40.00	106	949	91	249531
124	PR1:4	5.1836	3-Hexen-1-ol, formate, (Z)-	409062963	>0.08%	7:09.90	128	773	82	188113
165	PR1:4	4.4147	1-Decene	348384460	>0.08%	10:26.60	140	937	57	62018
247	PR1:4	4.3707	1-Dodecene	344911284	>0.08%	20:36.10	168	934	43	72250
23	PR1:4	4.2684	Aziridine, 1-(2-buten-2-yl)-	336840093	>0.08%	1:54.70	97	858	56	308327
252	PR1:4	3.8394	Tridecane	302981856	>0.08%	21:02.00	184	884	57	129901
228	PR1:4	3.7202	2,4,6,8-Tetramethyl-1-undecene	293579323	>0.08%	17:13.40	210	876	43	67253

5. Conclusion and Recommendation

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The extraction of fuel and different other components have been carried out through the pyrolysis of plastic waste, the objective of the pyrolysis was achieved since fuel was obtained at the end and analysed for its chemical composition. The conclusions that follow were observed; the different types of plastics displayed the presence of many different components within their structure, the number of components that can be observed from the degradation process also shown to be dependent on the intensity of the heat. Even though the experiment was successful there are possible areas of improvement so as to optimize the process. First of all, a catalyst should be used to improve the degradation process and lower the degradation temperature, similar types of plastics should be heated per batch in order to reduce the variability of components per sample, lastly the temperature should be kept consistent at about 350-400 degrees to influence liberation of common type of fuel.

References

1. Amte, V. Nistala, S. Mahajani, S.M. Malik, R.K. Optimization based conceptual design of reactive distillation for selectivity engineering, Computer Aided Chemical Engineering 28 (2010) 1237-1242.
2. Asiedu, N. Hildebrandt, D. Glasser, D. Experimental simulation of a two-dimensional attainable region and its application in the optimization of production rate and process time of an adiabatic batch reactor, Industrial and Engineering Chemistry Research, 53 (2014) 13308-13319.
3. Beneke, D.A. Abbas, R. Hildebrandt, D. Glasser, D. Design and analysis of multiple thermally coupled configurations using column profile maps, 2011 AIChE Spring Meeting and 7th Global Congress on Process Safety, 11AIChE; Chicago, IL; United States; 13 March 2011 through 17 March 2011.
4. Book, N.L. Challagulla, V.U.B. Inherently safer analysis of the attainable region process for the adiabatic oxidation of sulfur dioxide Computers and Chemical Engineering, 24 (2000) 1421-1427.
5. Chimwani, N. Mulenga, F.K. Hildebrandt, D. Glasser, D. Bwalya, M.M. Use of the attainable region method to simulate a full-scale ball mill with a realistic transport model, Minerals Engineering, 73 (2015) 116-123.
6. Danha, G. Hildebrandt, D. Glasser, D. Bhondayi, C. A laboratory scale application of the attainable region technique on a platinum ore, Powder Technology, 274 (2015) 14-19.
7. Godorr, S. Hildebrandt, D. Glasser, D. McGregor, C. Choosing optimal control policies using the attainable region approach, Industrial and Engineering Chemistry Research, 38 (1999) 639-651.
8. Hamid, M.K.A. Sin, G. Gani, R. A New Model-Based Methodology for Simultaneous Design and Control of Reaction-Separation System with Recycle, Computer Aided Chemical Engineering, 26 (2009) 839-845.
9. Hlabangana, N. Danha, G. Hildebrandt, D. Glasser, D. Use of the attainable region approach to determine major trends and optimize particle breakage in a laboratory mill, Powder Technology, 291 (2016) 414-419.
10. Hildebrandt, D. Glasser, D. The attainable region and optimal reactor structures, *Chemical Engineering Science*, 45 (1990) 2161-2168.

ISSN: 2521-229X
ISBN: 978-99968-0-608-7

11. Hogg, R. Fuerstenau, D.W. Power Relations for tumbling Mills, Trans, SMEAIME, 252 (1970) 418-432.
12. Kauchali, S. Rooney, W.C. Biegler, L.T. Glasser, D. Hildebrandt, D, Linear programming formulations for attainable region analysis, Chemical Engineering Science, 57 (2002) 2015-2028.
13. Kauchali, S. Hausberger, B. Hildebrandt, D. Glasser, D. Biegler, L.T. Automating reactor network synthesis: Finding a candidate attainable region for the water-gas shift (WGS) reaction,