

## **SUPERVISOR DECLARATION**

–I hereby declare that I have read this thesis and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Plant and Maintenance)”

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DESIGN OF REACTOR FOR PLASTIC RECYCLING THROUGH PYROLYSIS  
PROCESS

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A thesis submitted in partial fulfillment of the requirement for the award of the degree of  
Bachelor of Mechanical Engineering (Plant & Maintenance)

Faculty of Mechanical Engineering  
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## DECLARATION

I declare that this thesis entitled “*Design of Reactor for Plastic Recycling through Pyrolysis Process*” is the result of my own research except summaries and quotations which have been acknowledged.

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*Praised to Allah the almighty and to my beloved Father and Mother,  
And my beloved siblings and friends*

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## ABSTRACT

The design of reactor for plastic recycling through pyrolysis process is developed in this study. The main purpose of this study is to design a reactor that can be used for plastic recycling. The pyrolysis is a thermal degradation process in absolute absence of an oxidizing agent. This study enlightens the recycling of polymer which is polypropylene and polypropylene through pyrolysis process. The development 3D design of the reactor was using SolidWork 2013 software and has been analysed through two analyses by using ANSYS 15 software which are heat transfer analysis and thermal stress analysis. The highest temperature that has been detected on the design is 401.7°C and the lowest temperature was recorded was 26°C. For thermal stress analysis, the maximum equivalent stress of the design has been determined which the maximum stress is 208.84 MPa. The overall safety factor of the entire reactor design is 1.4844 for the minimum and 15 for the maximum. The design also has been fabricated by using conventional lathe machine and the performance of the prototype had being evaluated. The performance evaluation was conducted three times. The oily polypropylene condensed when the temperature of heating is 430°C and the mass of pure solid polypropylene that has been heated was 20g. The total condensed of polypropylene after two hours of heating is 6.7ml. However, the fuel turns back into solid state as the pyrolysis process may in premature. At the end of this paper will provide a design of prototype pyrolysis reactor that can be used in chemistry laboratory for academic purpose.

## ABSTRAK

Sebuah reka bentuk reaktor bagi tujuan kitar semula plastik melalui proses pirolisis telah dihasilkan dalam kajian ini. Tujuan utama kajian ini adalah untuk menghasilkan sebuah reka bentuk reaktor yang boleh digunakan untuk kitar semula plastik. Pirolisis adalah satu proses penyahgradasi termal dalam ruang ketidakhadiran agen oksidasi. Pirolisis merupakan teknik kitar semula yang tidak memerlukan agen oksidasi dalam pembakaran. Kajian ini juga menerangkan tentang polimer yang sering digunakan iaitu polietilin dan polipropilin. Penghasilan reka bentuk reaktor telah menggunakan perisian SolidWork 2013 dan melalui analisis pemindahan haba dan tekanan termal dengan menggunakan perisian ANSYS. Suhu tertinggi yang dicatatkan dalam analisis pemindahan haba ialah  $401.7^{\circ}\text{C}$  manakala suhu terendah adalah  $26^{\circ}\text{C}$  dan bagi kajian tekanan termal, tekanan sama tara pada reka bentuk reaktor adalah 208.84 MPa maksimum. Faktor selamat minimum bagi reka bentuk tersebut ialah 1.488 dan maksimum 15. Bagi penghasilan prototaip, mesin larik telah digunakan sepenuhnya bagi penghasilan geometri dan juga bebenang yang menjadi penhubung kepada kesemua bahagian reaktor. Ujian keberkesanan telah dilakukan sebanyak tiga kali. Titisan minyak daripada polipropilin terhasil selepas pembakaran 20g pepejal polipropilin dengan suhu  $430^{\circ}\text{C}$ . Kondensasi selama dua jam pemanasan telah menghasilkan 6ml meminyak polipropilin. Walau bagaimanapun, meminyak yang terhasil daripada proses pirolisis tersebut kembali ke fasa pepejal. Diakhir kajian ini, sebuah reaktor prototaip pirolisis yang akan digunakan di makmal kimia bagi tujuan akademik.

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## CHAPTER I

### INTRODUCTION

#### 1.0 BACKGROUND

Nowadays, plastic recycling is the main issue of the world. The trashes that contributed by the human. The rubbish that been thrown widely from human daily life is the major factor of the polluted situation today. According to (Correy.R 2012), the world is consuming about 600 billion pounds of plastic annually and at the same time the market is still growing about 5% a year. The pyrolysis process is one of the recycle methods that reliable nowadays.

Recycle is the most effective way on reducing the consumption of plastic. Most of developing country in this world had jump and invest in recycle development. It will give much costing reduction and can also increase the economy of the country. Based on Eurostat 2010, the recycle development is driven by the increasing of recyclable demand as the Asian economies helps to increase the price of the material. Furthermore, another driver has been Europe waste directives, which have contributed by creating compulsory to recycle for recover the increment percentages of waste, and discouraging landfilling. As a consequence, the amount of recyclables sorted and placed on the market has increased 15 % between 2004 and 2009

The further recycle development has also shows for the energy consumption. The daily waste that using plastic bag can even converted into lithium ion battery (Brett 2009). The previous study of thermochemical has come out with new thermochemical process that can convert the waste such as plastic and bio waste into biodiesel fuel.

According to (Passalaqua et al, 2013), pyrolysis is usually devoted to bio-oil production. As bio-oil is characterized by high energy density, the pyrolysis has received increasing interest in recent years compared to bulky biomass. Hence, the reactor of the pyrolysis can be the main focus of pyrolysis industry.

## **1.1 PROBLEM STATEMENT**

The existing prototype reactor in UTeM Chemistry Laboratory is for biomass pyrolysis process. It is not suitable to use in plastic recycling through pyrolysis process as the reactor use different sample of material that to be burnt. The main purpose of existing reactor is for converting biomass into biodiesel fuel. The reactor that needs to be designed must suitable to burn plastic for recycles purpose.

Apart from that, the existing reactor was designed not following the mechanic specification and also not based on heat transfer condition. Hence the design need further study to ensure the mechanic and heat transfer of the reactor is suitable for plastic recycling through pyrolysis process.

## **1.2 OBJECTIVES**

- 1.2.1 To obtain information about process parameters for pyrolysis process.
- 1.2.2 To design a reactor and optimize the design based on finite element analysis.
- 1.2.3 To fabricate a functional pyrolysis prototype reactor.

### **1.3 SCOPE OF STUDY**

The scope of this report is all about plastic recycling reactor. The materials need to be used during the process are Polyethylene and Polypropylene. Polyethylene and Polypropylene are commonly used in human daily life. They also categorised as thermoplastic material.

Apart from that, this report focuses on design optimization of reactor that cover mechanic and heat transfer. The mechanic include of pressure, fatigue and factor of safety. The heat transfer part will include the method of heat transfer and the most suitable temperature that will be used during the pyrolysis process.

This report also focuses on fabrication of a pyrolysis prototype reactor that will be used in Chemistry Laboratory in UTeM. The prototype must also suitable to be adapted with available furnace in Chemistry Laboratory. This is to ensure that the plastic recycling through pyrolysis can be done effectively.

### **1.4 REPORT ORGANIZATION**

The first chapter of this report has discussed about the general of the project. The background of this report explains about the importance of conserve the environment by developing recycle project. Apart from that, this chapter also discussed about the problems to be covered in this project. This chapter also has defined the objectives to be carried out for the whole report. The scope of study also has been stated clearly for enlighten the focus of this report.

The second chapter of this report has discussed about the previous research that has been done related to this project. The study on pyrolysis process that had been done by the previous researcher that gives much information on how the pyrolysis process happens. This chapter also described about the existence design of reactor that relate with the development of pyrolysis reactor.

The third chapter of this report is mainly about the methodology of the project. The progress is according to the flow chart that has been provided for the entire of the project. This chapter discuss on methods that being used in this project to achieve the expected result of the reactor design. The project will follow the procedure on analysis of heat transfer and mechanics. This chapter also state the method being used to fabricate the scale down prototype reactor.

The fourth chapter of this report is mainly about the development of the pyrolysis reactor design. The general geometry of the design was being explained in this chapter. Apart from that, this chapter will show the result of thermal stress analysis of the design. The result also is discussed in this chapter.

The fifth chapter of this report has discussed about the prototyping of designed pyrolysis reactor. The fabrication of each part of the pyrolysis prototype reactor was discussed generally according to the design that has been discussed early in fourth chapter. This chapter also show the performance evaluation of the pyrolysis prototype reactor.

The sixth chapter of this report has discussed about the conclusion of the reactor design for plastic recycling through pyrolysis process. This chapter enlighten the result regarding to the objectives of this project. Apart from that, the recommendation of this project also provided.



## CHAPTER II

### LITERATURE REVIEW

#### 2.1 INTRODUCTION OF POLYMER

Polymer is consisting of a long chain of repeating chemical units called monomers. The bonding between the one monomer to another may be in linear, cyclic and also branches. When the polymer undergoes polymerization, it is called a homopolymer. The examples of homopolymer are polyethylene, polypropylene and polystyrene. The polymer also divided into three types which are thermoset, thermoplastic and elastomer (Shakhashiri, 2012)

Thermoplastic polymer can be recycled and can be used again by break the chain of polymerization. The molecular chain of the thermoplastic material is not cross-linked to each other. Hence, with the application of a sufficient amount of heat, the thermoplastic can be moulded, shaped and extruded.

Polyethylene is characterized as a semi-crystalline polymer, made up of crystalline regions and amorphous regions. Crystalline regions are those of highly ordered, neatly folded, layered (in parallel) and densely packed molecular chains. These occur only when chains branching off the sides of the primary chains are small in number.

Within crystalline regions, molecules have properties that are locally (within each crystal) directionally dependent. Where tangled molecular chains branching off the molecular trunk chains interfere with or inhibit the close and layered packing of the trunks, the random resulting arrangement is of lesser density, and termed *amorphous*.

An abundance of closely packed polymer chains results in a tough material of moderate stiffness.

The melting point of polyethylene is defined as that temperature at which the plastic transitions to a completely amorphous state. Polyethylene is one of thermoplastic polymer.

Polypropylene is a polymer produced by the addition polymerization of propylene,  $\text{CH}=\text{CHCH}_3$  (propene). Its molecular structure is similar to that of polyethylene, but has a methyl group ( $-\text{CH}_3$ ) on alternate carbon atoms of the chain. Its molar masses fall in the range 50 000 to 200 000 grams. Polypropylene is slightly more brittle than polyethylene, but softens at a temperature about 40 °C higher. This polymer is used extensively in the automotive industry for interior, instrument panels and in food packaging. (Shakhashiri, 2012).

Table 2.1: Material used in Pyrolysis

Resin	Thermo Fuel System Suitability
Polyethylene	Very good
Polypropylene	Very good
Polystyrene	Very good(gives excellent fuel properties)
ABS Resin	Good. Require off-gas counter measure
Polyvinylchloride	Not suitable, should be avoided
Polyurethane	Not suitable, should be avoided
Fiber Reinforced Plastics	Fair. Pre-treatment required to remove fibers
PET	Not suitable, should be avoided



Figure 2.1: Polypropylene (left) Polyethylene (right) (Yin.L.J, 2014)

## 2.2 PYROLYSIS PROCESS

Thermofuel is a truly sustainable waste solution, diverting plastic waste from landfills, utilizing the embodied energy content of plastics and producing a highly usable commodity that, due to its cleaner burning characteristics, is in itself more environmentally friendly than conventional distillate.

According to Thoray P.V. et al, 2013 in their journal, pyrolysis is a process of thermal degradation in the absence of oxygen. According to numerous experiments of waste plastics pyrolysis, it has been found that their volatile evaporation stage is similar to water evaporating from molten polymer evaporation that characterized with formation of bubble evaporation on a well-heated surface.

Based on these characteristics, an innovative vertical falling film pyrolysis reactor was proposed. The vertical falling film reactor for waste plastics' pyrolysis consists of vertical tubes in parallel with round or rectangular outer frame. The molten plastic falls down along the inside of tube surfaces, and the hot gas flows outside the tubes. There is no movable parts inside the reactor therefore the reactor is safe and suitable for large scale. Applying this vertical falling film reactor to molten plastic pyrolysis cannot only improve the heat transfer efficiency, but also can solve the flow problem easily. (Yin. L.J, 2014)

Plastic waste is continuously treated in a cylindrical chamber and the pyrolytic gases condensed in a specially designed condenser system to yield a hydrocarbon distillate comprising straight and branched chain aliphatics, cyclic aliphatics and aromatic hydrocarbons. The resulting mixture is essentially equivalent to petroleum distillate. The plastic is pyrolysed at 370°C- 450°C and the pyrolysis gases are condensed through a distillation tower to produce the distillate.

According to Grammelis. P, 2007, for biomass pyrolysis, the temperatures needed to run the process is about 400°C to 800°C. Gas, liquid and solid char are produced, the relative proportions of which depend mainly on the reaction parameters of temperature and reaction time as well as of the rate of heat transfer to biomass feedstock.

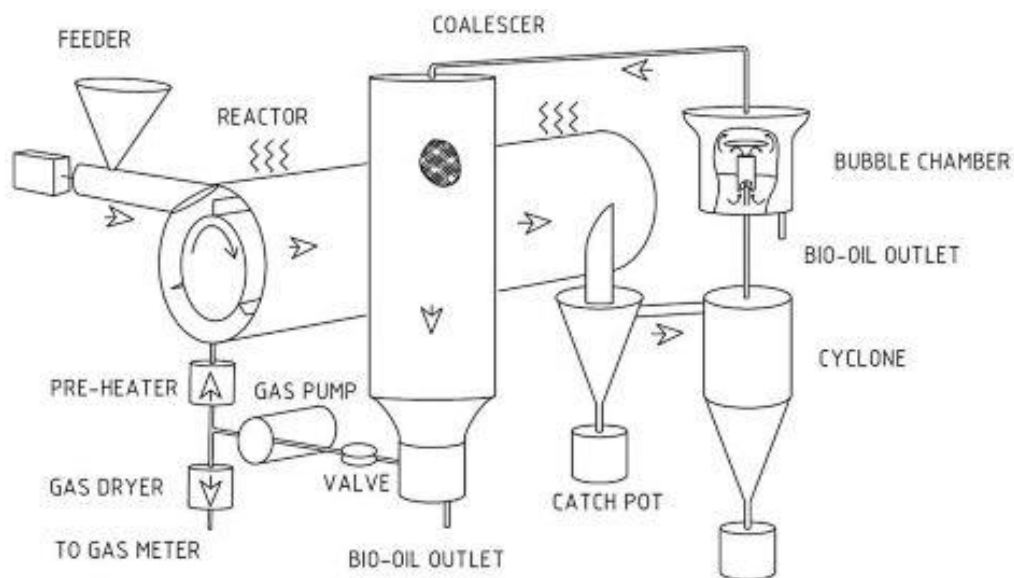


Figure 2.2: Fast Pyrolysis Process (Bech.N, 2009)

### 2.3 DESIGN OF REACTOR

Three major high-pressure wire-mesh studies had been completed by the mid-1980s. The initial reactor was constructed by Howard and co-workers (Suuberg *et al.*, 1980) not operate at heating rates below about 200°C and they relied for tar yield

determinations on deposition onto reactor linings and in the gas filters. Recirculation of tar vapors around the mesh could not be avoided. Initially, the high-pressure wire-mesh reactor designs were to examine the possibilities of hydrolysis as a process route for making liquids and substitute natural gas.

Hydrolysis was one of the research strands pursued in Europe and North America in the decade following the war of 1973 in the Middle East and the subsequent oil price increases. Pure high-pressure hydrogen was to be reacted with coal, to produce primarily methane and a tar. The suitability of the tars as a source of synthetic fuels and chemicals was to be explored. With the benefit of hindsight, it is not clear how this scheme was ever conceived as a process route with economic potential. In the first decade of the new millennium, we find ourselves in a quest for the “hydrogen economy”, wishing for large amounts of pure hydrogen shorn of its “undesirable” companion, the carbon atom.

Nevertheless, in the mid-1980s, hydrolysis was investigated by British Gas and a consortium including several Japanese companies, led by Osaka Gas. At the time, the Japanese gas industry was looking into technically viable alternatives to the massive 2 imports of LNG, which they later committed themselves to. A 2-ton per day pilot entrained flow reactor at Solihull (UK) was followed by a 50-ton per day facility in Osaka.

The Japanese government having initially pledged about \$125 million for this development, eventually abandoned the project early in the new century. In the summer of 2001, Syngenta was still putting out feelers for relaunching bench scale hydrolysis research. This occurred when natural gas prices had temporarily spiked to around \$10 per million BTU. At the end of the summer, however, gas fell back to about a third of that price and interest waned. Notwithstanding these economic ups and downs, hydrolysis was one of the technically most successful applications of the wire-mesh reactor configuration.

Experimental high-pressure fluidized-bed systems usually consist of a heated reactor body surrounded with thermal insulation to protect the outer “cold” pressure casing from elevated temperatures. This is done to distance the pressure containment problem from parts of the system where temperatures are high. At or near ambient

temperatures, containment vessels operating at pressures required by gasification tests do not require exceptional alloys or very specialized designs.

On the other hand, such assemblies usually turn out to be bulky. These larger rigs usually require several operators alongside relatively complex instrumentation. The high construction costs and accompanying expenses would, at least in part, explain the relatively small number of such units in existence.

## 2.4 PREVIOUS STUDY

Bech et al in their study discussed about the flash pyrolysis process of straw and wood by using pyrolysis centrifugal reactor. The paper discuss about the modelling solid convective flash pyrolysis. The model describes the presented experimental results adequately for engineering purposes for both wood and straw feedstock even though conditions for ablative pyrolysis from a reaction engineering point of view are not satisfied. Accordingly, even though the concept of an ablative melting particle may constitute a limiting case, it can still be used to model flash pyrolysis provided that the reacting particle continuously shed the formed char layer.

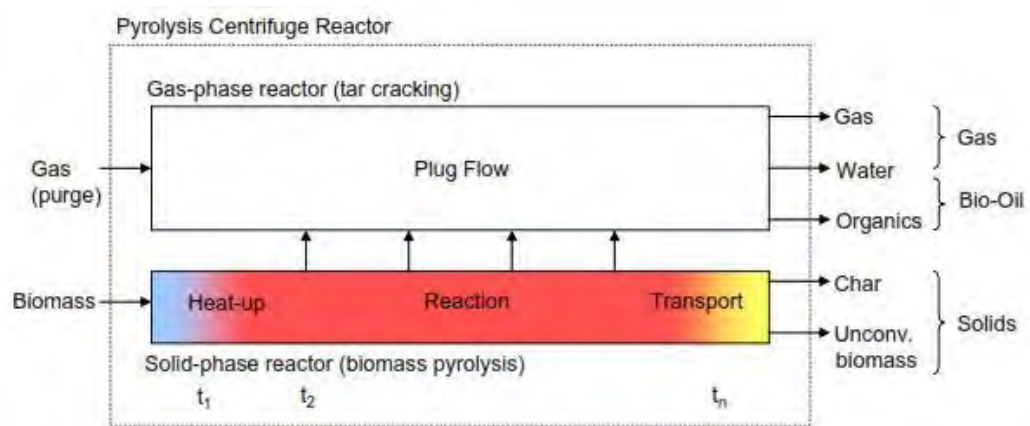


Figure 2.3: Model outline for biomass (Bech, Lasen, Jensen, & Dam-Johansen, 2009)

Mass balance closures were generally good for both wood and straw experiments with average losses of  $7.6 \pm 2.2\%$ wt. and  $2.8 \pm 2.2\%$ wt., respectively, and in all cases the loss was positive. However, in order to assign the balance for modelling purposes the ultimate analysis presented in Table 3 was used to compute the composition of the lost material. The analysis revealed that based on the organic constituents the lost fraction had a composition similar to char, although with an increased hydrogen content, and therefore it was assumed that the loss was due to condensation of vapours on the reactor pipe flanges which were somewhat inadequately insulated and prone to promote condensation. Thus, in the following material not collected experimentally has been assigned to char. Assigning the observed loss to char was apparently contradicted by an ash mass balance which would overestimate the amount of ash. However, detailed analysis of the ash in the parent material and the two products revealed that for all components except silica and iron the distribution between the products was roughly equal. It is therefore believed that the ash observed in the liquid product resulted from leaching of inorganic components from carried-over char (roughly 10–15%wt. of total char yield) before it was removed by filtration and quantified. However, since silica is expected to be present in the form of SiO<sub>2</sub> which is insoluble in the mildly acidic bio-oil this component was retained in the solid phase. The highly increased amount of iron in the two products could likely originate from either wear on the reactor pipe from particle movement or corrosion of the equipment by bio-oil. A result for pine wood includes the limits of a credible interval established by repeating an experiment five times with fixed reactor parameters at 550°C and for each product estimating the interval as twice the standard deviation. Rather than calculating error bars for each experimental observation based on the analytical uncertainty, this procedure was thought to give a more correct picture as the observed experimental scatter seemed to arise from experimental variations and not from the analytical methods. It also can be seen that the model accurately predicts the yield of gas in the entire investigated domain and to a lesser extent also of organics and char. For the latter two the predictions appear to be biased such that above approximately 550°C organic yields are overestimated whereas char yields are too conservative. A possible explanation could be the before-mentioned condensation of organics on the reactor internals. However, given that the main discrepancy between model and experimental results is observed for the single experiment at 575°C and that the mass balance was closed

with char, it is uncertain whether this is the result of poor collection of organics for this data point. In any case the model appears to be satisfactory for engineering purposes. Due to the lack of published kinetic data for wheat straw, it was attempted to employ the superposition kinetic scheme. By dividing each size fraction into its three main organic components cellulose, hemicellulose, and lignin and modelling each separately using kinetic data for the pure components the result was obtained by averaging over composition and then particle size. However, not unexpectedly this approach proved unsuccessful properly because the influence of ash components is of more importance than the organic composition for the yield of products. Interestingly, for pines the simple cellulose kinetics more accurately described the experimental results than the detailed superposition model. Accordingly, it was decided to use the cellulose kinetic data which had been given wood results with wood but modify them to obtain an acceptable fit. It has been reported that the alkali metal content in herbaceous biomass has a pronounced catalytic effect on the pyrolytic reactions favouring the formation of char and gas the activation energies by 14% and 4.5%, respectively, produced an acceptable fit but could likely be improved by investigating the kinetics for straw in more detail.

Wang et. Al, 2014 were discussed in their paper is on innovative reactor that will process the waste plastic through pyrolysis process. The model is consisted of vertical tubes in parallel together with the molten plastic (thermoplastic) which would condense along the inner wall at the same time it evaporate to finish pyrolysis process. During numerous experiments of waste plastics pyrolysis, it has been found that their volatile evaporation stage is similar to water evaporation that characterized with bubble formation evaporation on a well-heated surface. Based on these characteristics, an innovative vertical falling film pyrolysis reactor was proposed.