

Design and Analysis of Waste Plastic Pyrolysis Reactor

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Abstract — In recent decades, there has been a dramatic increment in a plastic consumption. Used plastic is one of the major wastes in many countries including, India. Lot of money is been spent to landfill these plastic waste which can cause a environmental pollution in a long run as since its takes decades of time to get disposed. The impact of plastic waste is very critical for humans as well as for environment. Disposal of waste plastics had become a great concern for everybody as it takes decades to decompose if left as its own. On the other hand, continuous increase in Industrialization and Urbanization has created a measurable raise in demand of fuels. Nowadays it has become a need to seek the alternate energy sources in the place of conventional fuels. The above problem can be under covered with the help of pyrolysis system. The detailed analysis and design of pyrolysis system will help to develop a system, which is highly efficient and economic as compared to other processes. The proper Design and Analysis of the system would also allow to determine and control the key factors, responsible for the entire process of pyrolysis. It will provide a proper design data for the development of the system on the basis of various application and for varying capacity of Bio-Fuel production.

Keywords—Waste Plastic, Plastic Pyrolysis, pyrolysis Plant Plastic bio-oil, Pyrolysis Reactors, Pyrolysis CFD

I. INTRODUCTION

Plastic is one of the most hazardous substances for our environment. It can be considered as a “Time Bomb”. *What if the plastic waste didn't have to impact the world in critical way?* As these helps in stepping ahead in the field of renewable energy with the adaption of advanced technology to convert plastic waste into Bio- Fuels. The same is achieved by the process called Pyrolysis in a reactor called pyrolyzer. Plastic was invented in 1862 by Alexander Parkes [1]. They are formed by polymerization and have high molecular mass. Other substances may be present in plastic besides polymer to minimize cost and to enhance performance. Plastics are one of the most commonly used materials in our daily life, as they contribute to make our life easy and convenient. They are widely used in packaging and manufacture of products including electronic, automotive, etc.[2] plastics are light in weight and can be simply formed. They can be reused and help to conserve the natural resources [3]. Plastic pyrolysis involves heating and degradation of plastic polymers at temperature between 350°C and 900°C in an oxygen deficient environment [3]. Mainly there are two types of plastics: thermosetting and thermoplastics polymers. Thermosetting plastics can be melted and shaped only once. It's not good to repeatedly heat treat such plastics, therefore they remain in solid state after they have been solidified, if enough heat is supplied, thermoplastics can be softened and melted repeatedly. On cooling, they are hardened, so they can be used for new plastic products. Society of Plastics Industry (SPI) has divided plastics into following groups on the basis of application and chemical structure [4].

1	2	3	4	5	6	7
PETE	HDPE	PVC	LDPE	PP	PS	OTHER
polyethylene terephthalate	high-density polyethylene	polyvinyl chloride	low-density polyethylene	polypropylene	polystyrene	other plastics, including acrylic, polycarbonate, polyacrylic fibers, nylon, fiberglass
soft drink bottles, mineral water, fruit juice containers and cooking oil	milk jugs, cleaning agents, laundry detergent, bleaching agents, shampoo bottles, washing and shower soaps	trays for sweets, fruit, plastic packing (bubble foil) and food bags to wrap the foodstuff	crushed bottles, shopping bags, highly-resistant sacks and most of the wrappings	furniture, consumers, luggage, toys as well as bumpers, lining and external borders of the cars	toys, hard packing, refrigerator trays, cosmetic bags, costume jewellery, audio cassettes, CD cases, vending cups	an example of one type is a polycarbonate used for CD production and baby feeding bottles
						

Fig. 1 Different Types of Plastic [5]

II. PYROLYSIS PROCESS

Pyrolysis is the chemical decomposition of organic substances derived from Greek word Pyro “fire” and Pyrolysis “decomposition”. It's usually the first chemical reaction that occurs in the burning of many solid organic fuels, wood, paper, and some kinds of plastics pyrolysis process can also be used to produce the liquid fuel know as bio fuel which can be mixed with a diesel in 30:70 from the plastic waste i.e. oil obtained. This technology is thermal degradation process in the absence of

oxygen; plastic waste is treated in cylindrical reactor at a temperature upto 400°C-450°C. Nowadays plastic waste is very harmful to our nature also for human beings plastic is also not easily decomposable it's affect in fertilization, atmosphere, mainly effects on ozone layer so it's necessary to recycle the plastic in useful things so we recycle into a useful fuel [6].

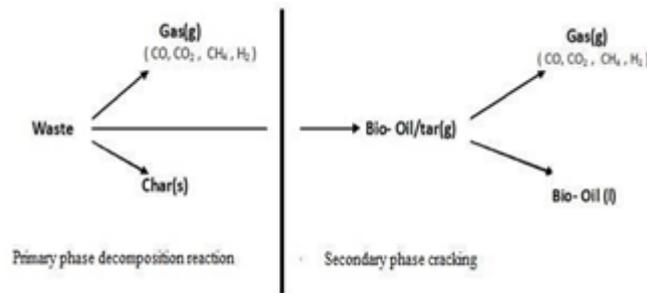


Fig. 2 Reaction paths of Waste Pyrolysis

III. DESIGN

Design of Fluidized Bed Fast Pyrolysis Unit

The first step in the design was the choice of reactor type. A typical pyrolysis unit comprises feedstock handling and pre-process like segregating, grinding of feedstock in fine particles are needed, it's heating and finally pyrolysis. Energy required in each step was estimated as per the methodology [6].

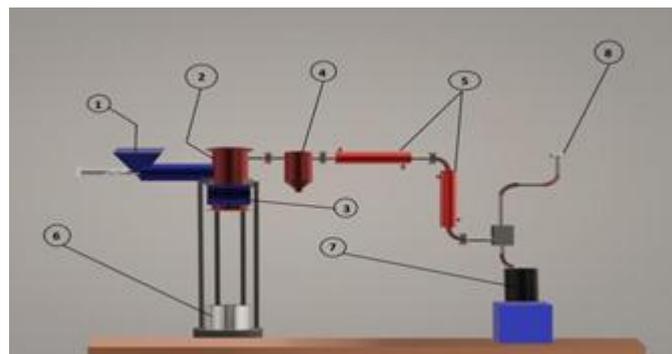


Fig. 3 3D Model of Pyrolysis system

Table 1 Indication table of Fig. 3

Mode of operation	Fluidized Batch type
Phase present	Heterogeneous
Process	Fluidized bed
Operating pressure	Internal pressure (0.8MPa) (design assumption)
Operating temperature	Temperature (400°C - 450°C)
Operating condition	Closed
Geometrical shape	Cylindrical
Orientation	Vertical
Wall thickness	Thin wall
Heating method	Coil heater
Fabricating material	Mild Steel
Location	Field equipment



Fig. 4 Pyrolysis Reactor

Table 2 Design Overview of Reactor

1	FEED STOCK WITH SCREW FEEDER	5	CONDENSER
2	REACTOR	6	ASH COLLECTOR
3	GLASS WOOL COVER	7	BIO-OIL COLLECTOR
4	HEATING COIL	8	BURNER

General Design Overview of the Reactor

As a chemical reactor is a specific type of pressure vessel. Considering the application, the reactor can be classified considering various facts. For the reactor design of conversion of waste plastic into fuel oil and gas, the above design overview will be considered.

Design of Reactor Geometry

The pyrolysis reactor was designed to have a vertical cylindrical cross section, called as shell. Both top and bottom heads are flat and fitted with a bolt both the heads were flat so there will be a lesser cost. The reactor was designed (assumed design pressure) 8 bar and to ensure that the greater rate of heat transfer is allowed pressure gauge were attached at the top and piping was provided for vapor to condenser and for the removal of char. The entire model was made in the AutoCAD 2017.

Heating System

Here the heating system was taken as an electric coil heater which was designed as per the reactor dimensions so that the maximum amount of heat transfer will take place with a minimum loss, also the glass wool design was also considered so that there would be no heat loss from the coil heater. The different temperature of coil at a particular time was done through CFD to see the Temperature, Velocity and Pressure Profile. As Scheirs et al. [7] stated that gases formed during the pyrolysis of organic materials include carbon monoxide, carbon dioxide, water, hydrogen, methane, ethane, propane, propene, butane, butene, etc. the temperature and rate of heating can be controlled to produce desired solid, liquid and gas products because they have significant influence in the pyrolysis process [7].

Design of Reactor

Thickness of reactor shell, [8] $t = \frac{P \times r}{S \times E - 6 \times P}$

Weld Joint Efficiency, E = 70 % for butt joints

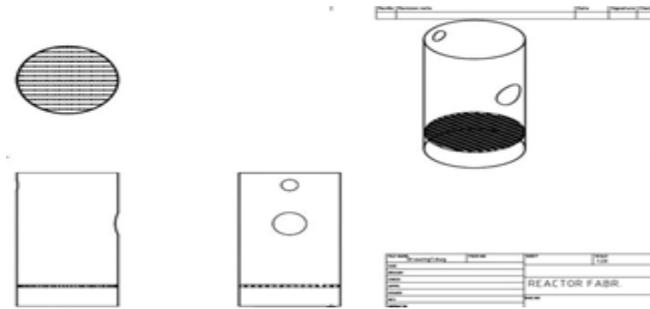


Fig. 5 Design of Reactor

IV. ANALYSIS

Introduction

CFD stands for Computational Fluid Dynamics. It is one of the most essential factors used in engineering applications. The gaseous and liquid flow is quantified and determined using partial differential equations representing conservation of mass, momentum and energy this technique of analysis. CFD is based on the concept of “Navier Stokes Equations” [9].

CFD Analysis

The design Analysis of pyrolysis reactor is a CFD tool named ANSYS18.1 Workbench. The CFD tool found to be more reliable in the sense of measuring the operational parameters of our reactor because after designing a system, it's parameter and it's behavior at variable operational conditional needs to be determined to have a proper knowledge of proper designing and functioning of the reactor. CFD tool help to determine various parameter effecting performance of our system. With the help of CFD tool we have determined the Heat Flow, Temperature, Pressure and Velocity at different sections of our pyrolysis system.

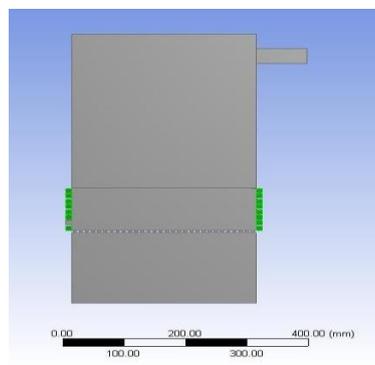


Fig. 6 2D View of Pyrolysis Reactor

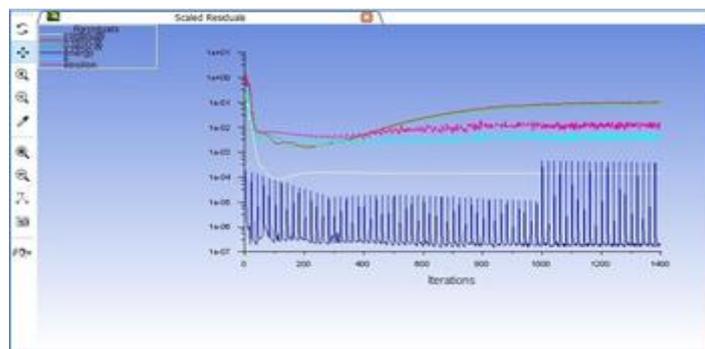


Fig. 7 Residuals

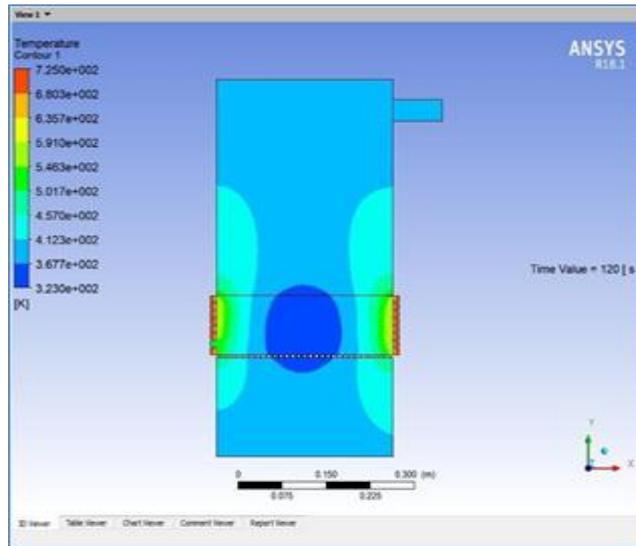


Fig 8 Temperature at 120 sec

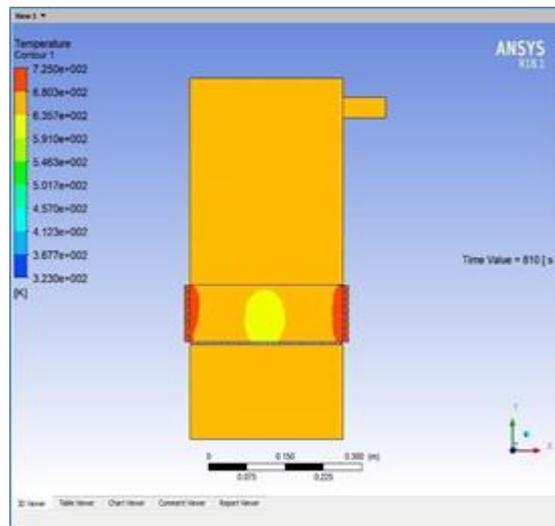


Fig 8 Temperature at 810 sec

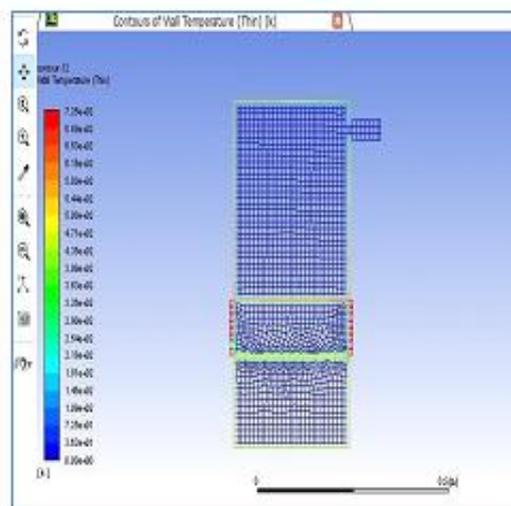


Fig. 9 Wall Temperature

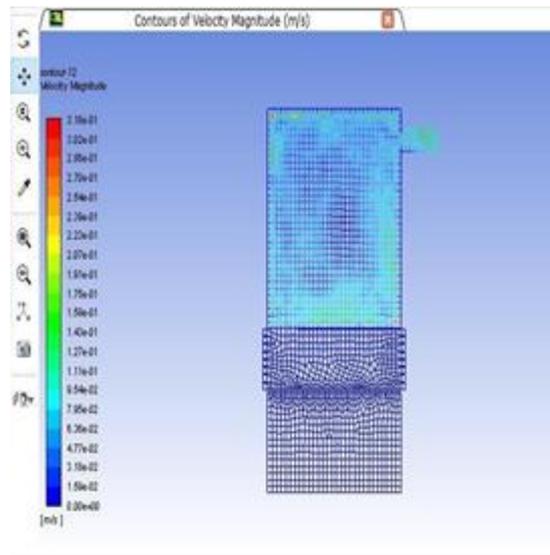


Fig. 10 Velocity Contour

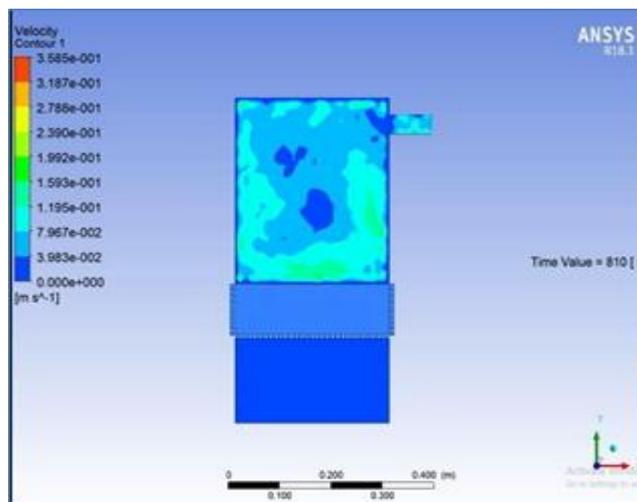


Fig. 11 Velocity at 810 sec

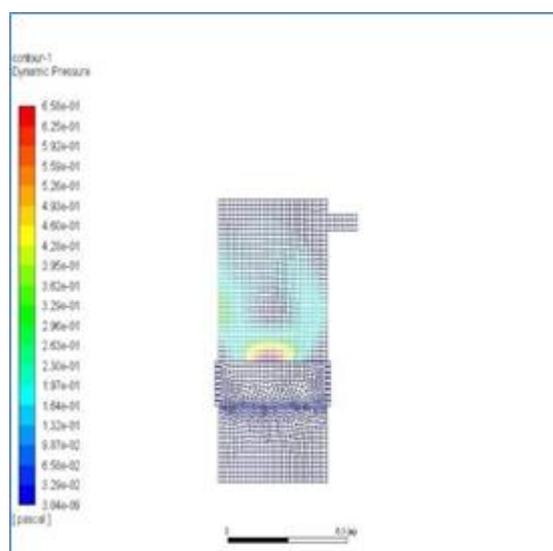


Fig. 12 Pressure Contour

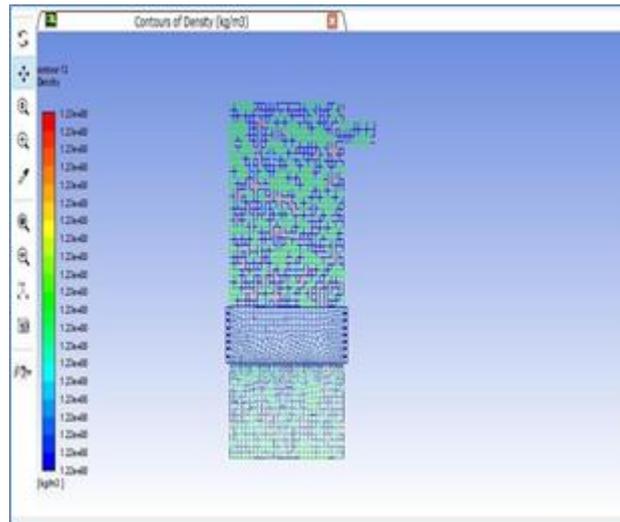


Fig. 13 Density

Outcomes from CFD Analysis

Parameters	Readings
TEMPERATURE (Outlet)	365°C (At 810 Sec)
VELOCITY (Outlet)	0.2 m/sec
DENSITY	1.23 kg/m ³
PRESSURE	0.27 Pascal
WALL TEMPERATURE	305°C
COIL TEMPERATURE	450°C (At 1020 Sec)

Table 3 Readings from CFD Analysis

CFD Analysis in ANSYS helps us to determine various necessary factors like effect of heating coil on reactor wall, safe operating pressure, behavior of reactor equipment, parts at specific temperature and pressure etc. to uncover the design aspects related to the safe operations of the pyrolysis system.

It has given detailed information regarding the different parameter.

Therefore to determine the critical factor is possible by simulation rather than practical aspects.

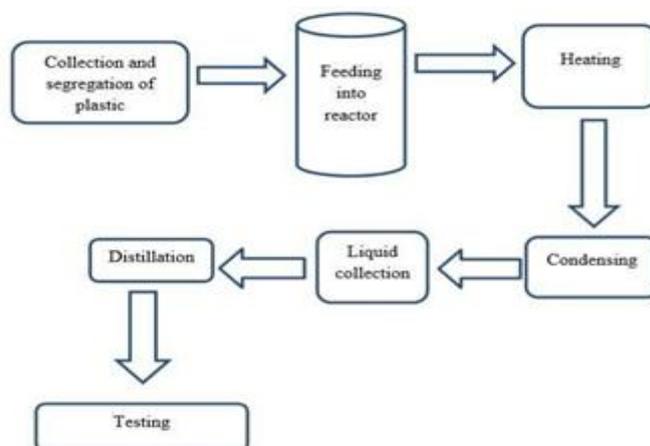


Fig. 14 Flow Diagram of Process [10]

Advantages

- The waste plastic is converted in fuels having high calorific value.
- The process is environment friendly.
- Plastic fuel can act as an alternate fuel to diesel, petrol and kerosene.
- Plastic pyrolysis fuel is cheaper than another fuel.
- Burning of plastic produce toxic gases like nitrogen dioxide, sulphur dioxide, dioxins and other harmful gases. Plastic pyrolysis process produces minimum hazardous gases, hence, the process help to control the environmental pollution.
- It solves the problem of disposal and management of waste plastic by converting into alternative source of energy.
- The plastic fuel can help in reducing the dependency on gulf countries for petroleum.

Limitations

- The process is time consuming.
- Plastic pyrolysis fuel cannot used directly in engine.
- Initial cost of machine is high.
- Identification of type of plastic is difficult.
- Fractional distillation process is complicated.

Application

- It can be used as an alternate source of fuel in diesel engines.
- It can be used in sugar industry, steel industryetc.
- It can be used as a fuel in diesel generators.
- It can be used for heating boilers.
- The application of this system could help in reducing the dependency on the gulf countries and promotes a step towards innovation.

V. CONCLUSIONS

- Plastic bears a major treat to the current scenario and environment. Millions of tons of plastics are produced on the daily basis and only few percentage of waste plastic is being successful recycled.
- Plastic take a long year to decompose, some alternative to plastic should be developed. Also, the world is facing the problem of shortage of petroleum.
- Conversion waste plastic into fuel can provide a better solution to a disposal problem of waste plastic as well as act as alternative to fossil fuel.
- From design and Analysis that by using this Pyrolysis method one can set a fabrication of small scale as per the CFD analysis shown above.
- The output may varies depending on the type of plastic used, the temperature which is heated to the reactor as the plastic fuel may showed the properties similar to that of diesel fuel.
- Pyrolysis of plastic into fuel can solve both the problem of plastic waste management as well as shortage of fossil fuel.

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