Waste Plastic to Liquid Fuel with Process Optimization

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Abstract

Today's world is facing a big problem of waste plastic & is consuming big size of land for its disposal too which is a major issue in front of society. Through this paper a developing technology of conversion of waste plastic into liquid fuel & its optimization with the help of Instrumentation Engineering & Chemical Engineering concepts is put forward.

The process of degradation of waste plastic with the help of thermo-catalytic cracking of bonds & conversion of plastic to liquid fuels named as "Waste Plastic Pyrolysis Oil" is called as Pyrolysis Process & is majorly depends on the process temperatures & catalyst used for the process as both the factors decides the output of the process.

By using this concept, we have carried various experiments & presenting some of results, showing how the process can be optimized with the temperature control & use of proper catalyst composition.

Keywords: Pyrolysis Process, waste plastic to fuel, Thermal cracking, catalytic cracking, plastic waste management.

Introduction

Major cities in India generates 100 to 200 tons of plastic waste per day which totals to 5.6 Million Tons per year (plasticnews.com). This is for Europe is 60 million ton per years and is huge in almost every country. In India we are producing thousands of Tons of plastic waste per day out of which only 40 to 50 % plastic is getting recycled & we are leaving 50 to 60% of plastic per day as it is without disposal which is resulting in huge plastic waste deposition on our land surface. In Europe 50 % of plastic waste is being used for the landfills & only 24 % of waste plastic is getting recycled.

The way of disposal of plastic as landfills creates lot of health hazards to the local community. Poly bags takes 400 years to get degraded and general plastics takes approx. 1000 years to degrade. The scrap waste generation in modern countries is very large. In US its about 30 to 35 million tons per year.

These wastes are even not biodegradable & Environment Protection law prohibit direct disposal because

- It can't be burnt as produces huge & poisonous gases causing air pollution
- It can't be buried in soil as it affects the soil fertility.

It can't be dumped in sea as is a hazard for sea life.

Dumping of plastic waste scraps at scrap yards is also a danger to society as many incidents occur where such yards catches fire & keep firing for several months with poisonous fumes and such fires are not even easy to extinguish.

Such yards also becomes a mosquito breeding ground which is a terrible problem for the developing countries like India.

Some more methods line incineration are also used for the plastic treatment & energy recovery but are not acceptable at all countries due to poisonous gas emissions from the process even after output gas processing plants.

Composition of plastic waste worldwide is given in below fig. 1.

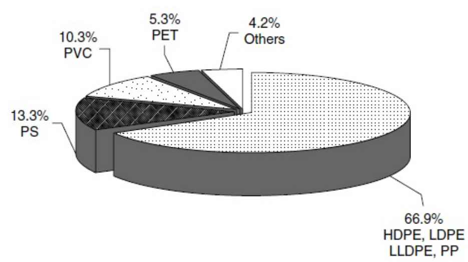

Fig. 1:- Composition of plastic waste available [A. G. Buekens et al. 1998]

Fig. 1 represents the waste plastic composition available worldwide.

These plastics are broadly classified in to two major categories.

1. Thermoplastics – These can repeatedly soften and melt if enough heat is applied and hardened on cooling, so that can be converted into new product. Polyethylene, polystyrene and polyvinyl chloride are examples of this.
2. Thermosets or thermosetting – These can be melt and shaped for only one time. They cannot be heat treated repeatedly. Phenol formaldehyde and urea formaldehyde are some of its examples.

Most of the plastic waste given above can be disposed in best way by pyrolysis process to convert it in fuel which helps society in by giving an efficient fuel as like crude oil & reducing so disastrous plastic waste scrap.

In pyrolysis process plastic waste of selected category is decomposed in the absence of oxygen in rector with the help of catalyst to break the bonds & convert it in to liquid which is nothing but pyrolysis oil. As most of the plastics are made from crude oil, degradation of such plastic in the absence of oxygen forces it to convert back in to the liquid fuel same as the crude oil in almost all the technical properties.

The process is carried out in the absence of oxygen as mention above just to avoid fire due to auto ignition properties of fuel at certain temperatures as the process is endothermic & uses large amount of heat for this degradation.

Catalyst is used for the proper bond breaking & extraction of crude oil from the plastic completely as if the bond breaking is not proper then the oil will not be extracted completely & the carbon residues from the process will contain some amount of oil which will again be dangerous in aspects of fire hazards & the loss of energy in the form of loss of oil from the process is another drawback.

Temperature plays a very important role in the pyrolysis process as the degradation of the plastic & extraction of oil is depend on the temperature too and the proper temperature & proper use of catalyst for the process defines the process time & off course the efficiency of the process & output too.

Various aspects which play a role in the process & its efficiency are listed below.

- Temperature of process
- Raw material composition
- Catalyst use composition
- Process time

Some other factors are

- Loss of fumes from the process while feeding
- Raw material feeding rate

If the plastic waste used is acidic in nature then the use of basic agent like CaCO3 is also an important factor to avoid the damage of reactor due to formation of acids in the process.

Unlike of the plastic type, process parameters and the method of pyrolysis process changes slightly but the main principle of the process remains same.

Material and technology details are explained below.

Materials & Methods

In market, PP, PE, LDPE plastic are widely available waste plastic materials and can be used for the conversion to fuel as these are not acidic in nature and contains good quantity of oil even at the last life cycle which increases the process output so are efficient for the process and for the industry too.

Below given table shows available types of plastic in the market & the required process for the degradation.

Polymer resins and major possible products of thermal decomposition

Resin	Mode of thermal decomposition	Low-temperature products	High-temperature products
PE	Random chain rupture	Waxes, paraffin oils, α-olefins	Gases and light oils
PP	Random chain rupture	Vaseline, olefins	Gases and light oils
PVC	Elimination of HCl from the chain, chain dehydrogenation and cyclization	HCl (<300°C), benzene	Toluene (>300°C)
PS	Combination of unzipping, and chain rupture, forming oligomers	Styrene and its oligomers	Styrene and its oligomers
PMMA	Unzipping	MMA	Less MMA, more decomposition
PTFE	Unzipping	Monomer	TFE
PET	β-Hydrogen transfer, rearrangement and de-carboxylation	Benzoic acid and vinyl terephthalate	
PA-6	Unzipping	Caprolactam	

Table 1:- Raw material & product chart [JOHN SCHEIRS et al. 2006].

From all these plastics, we are focusing PP, PE & LDPE materials due to its huge quantity (fig. 1), similar bong breaking process as per above table 1.

Below given Table 2 shows the percentage of fuel content in the PP & LDPE plastics.

Product distribution in the cracking of polyolefins at 400°C

Feedstock	Gas	Oil/wax	Residue
LDPE	20.0	75.0	5.0
PP	11.0	87.8	1.2

Table 2 :- Oil & wax content in raw materials

From Table 2, we can see the huge fuel content in the PP & LDPE plastics & is similar in the PE plastics too. These fuel contents are in huge quantity even in the last life cycle of the plastics too.

Pyrolysis Process:-

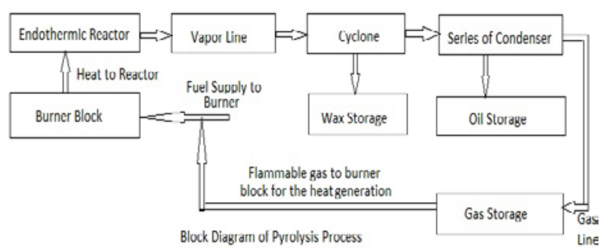

Fig. 2:- Block Diagram of Pyrolysis Process

Above block diagram shows the major component of process & process flow.

(1- Burner block, 2- ID fan, 3- FD to burner block line, 4- Endothermic reactor, 5- Vapor Line, 6- Cyclone, 7 & 8- Condensers series, 9- Gas line to gas storage, 10- Wax collection tank, 11- Oil collection tanks, 12- Gas line from gas storage to burner for firing, 13- Feeding hopper, 14- Carbon screw)

Fig 3:- Pyrolysis pilot plant – Kalamkars Energy Pvt Ltd, Koregaon, Satara [KEPL et al., 2016]. (Actual process experimentation done at above mentioned setup)

Above fig. 3 shows the plastic pyrolysis plant setup. The below is the description of the parts used in it.

Above is the complete list of basic pyrolysis plant setup.

Burner block is the part where we maintain the fire continuously to maintain the temperature of the reactor for the pyrolysis process and the temperature changes on the basis of raw material used in the process.

In general the temperature at the burner is maintained at around 700°C on the basis of material. [J. Aguado, et al., 2001].

ID & FD fans are used to keep air supply proper in the process. Heat exchanger is taking heat from the exhaust air and gives it to the atmospheric absorbed air for preventing the loss of heat.

Endothermic reactor is used for the pyrolysis process and the plastic is directly feed through the hopper in the reactor body for the process. In reactor the feeded plastic got melt and degraded to separate the bonds to get convert in to the liquid fuel. For the bond breaking process catalyst like zeolite helps in the reactor which is feed with the raw material itself [X. Li, et al., 2001].

Reactor motor starts after the reactor reach sufficient temperature after cold start of the reactor and if even the process holds for a longer time then also reactor motor starts after required temperature, this is because the raw material is plastic and it becomes solid block after feeding at certain low temperature and which can damage the reactor motor screw blades if the motor starts at some low temperature. This reactor motor screw helps to mix the molten plastic well inside the reactor with the catalyst to complete the degradation process well.

Vapor line is used for the passing of vapor through this line when the plastic gets converted into vapor form. These vapors are then passed through the cyclones and condensers to remove the oil from the vapors.

Cyclone is the first part after the vapor line and inside cyclone heavier particles of the vapor becomes dense first which gets converted into wax and is the byproduct is this process.

Condenser 1 is used for the condensation of the vapors and extraction of oil from the process. Condenser 2 is used for the more condensation of the vapors passed through the condenser 1 and the remaining oil is extracted here. Oil collected in condenser 2 is comparatively lighter in density than that of collected in condenser 1. Both the condensers are provided with the water supply in the outer jacket for the vapor condensation and the water supply is through the cooling tower.

After the condensation of the vapors the remaining fumes or we can say gases are just similar to the methane and are flammable. These gases are then passed through the pipeline from the condenser 2 to the gas balloon and are stored in the gas balloon. These stored gases can be used as a fuel for this process though the gas line from balloon to the burner system.

Wax collector tank is used for the removal of the wax form the cyclone but the condition is, wax must be removed in the process continuously else the pressure in the vapor line increases suddenly which may damage the process setup or even can cause accidents.

Oil collection tanks 1 and 2 are used for the removal of oils from the condenser 1 and 2.
Carbon screw is used for the removal of carbon from the reactor remain in the process of extraction of oil. This carbon is to be removed by purging nitrogen like agent in the carbon chamber, as the carbon from the reactor is at very high temperature due to the reaction there is a danger of fire hazards of carbon. So the Nitrogen is purged in the carbon chamber before the start of the process of carbon removal.

The gases from the burning process contain some hazardous gases and so can't be released directly to the open atmosphere. These gases are passed through the heat exchangers and the heat is exchanged with fresh air and the gases are dissolved in the water and then the remaining gases are released to the atmosphere. This water is also used for the process continuously and the fresh water is not needed every time so the wastage of water is also very little.

Various pinpoints of the Process & role of Instrumentation in it:-

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1. Process temperature is very important parameter & to control it is mandatory failing of which can make process unstable. Temperature is monitored continuously through J type thermocouples & the feedback is given to the controllers with which the fuel flow is regulated to control temperature of the reactor.

Fig. 4. given below shows the basic working principle of the temperature control for the reactor. Reactor is equipped with two thermocouples, one of which is given to the reactor core & another is given to the reactor outer shell. Thermocouple inside reactor measures reactors core temperature & another thermocouple measures the shell temperature, output of both is given to the recorder. We are continuously monitoring the temperature inside the reactor & if variation in same is needed, we change the set point of the burner controller as per requirement which controls the burner fuel supply by controlling fuel flow with fuel line control valve.

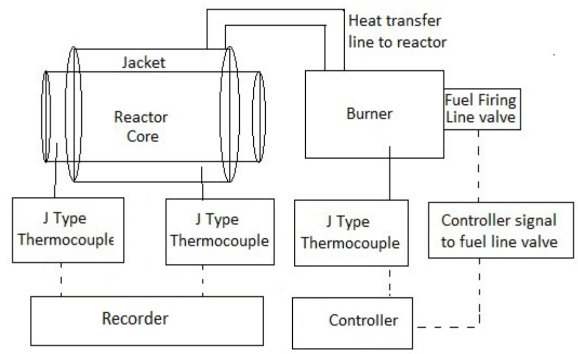

Fig. 4:- Temperature control for reactor - working diagram

2. Burner control is most important factor in this process as the burner directly affects the temperature of the process which is monitored with K type thermocouples as temperature rises above 700˚C, setting of which with proper setpoints is important to avoid continuous start & stop of the process, which reduces the quantity of fuel consumption.
3. Losses of fumes from the hopper while feeding are very dangerous and also reduces the process efficiency, the same can be controlled with the help of timer operated, normally closed logic knife edge gate control valve.
4. The pressure of the vapor line and the pressure of the condenser to balloon gas line are also very important aspects and can cause the explosion or similar kind of accidents in the plant & so to monitor pressure & to control it by releasing the cooling line valves releases the pressure in line..
5. Gas balloon pressure monitoring &

after pressure is built in the storage tank, use of the flammable gas for the firing in burner through compressor, filters & solenoids whic plays pressure building, filtering & flow regulating roles is the key factor in the efficiency increase of the process. .

6. Condenser fluid plays very important role in the oil particles condensation and so the flow of the fluid that is cooling tower water through the jacket continuously is very much important else the chances of pressure increase in the process can occur.
7. Carbon chamber purging is very essential as mention in previous section as the carbon is at very high temperature inside the reactor and if it tries to be removed without purging then the carbon will catch fire.
8. Reactor motor should start after reactor reaches particular temperature else the reactor motor or rotor blades may get damaged inside the reactor due to the formation of plastic block due to insufficient temperature to get it in molten state.
9. Cooling tower start is very much necessary when the burner temperature crosses the150̊C else the system will get heated and the motor bearings my get damaged.

All these things can't be monitored & controlled without Instrumentation & so it plays an important role in the process optimization [KEPL et al., 2016].

Influence of the Process variable:-

Various main parameter which affects the process are-

1. Temperature [A. Corma, et al., 2000].

2. Catalyst composition [X. Li, et al., 2001].

3. Raw material composition.
4. Process time.

These parameter affects the process & its output & so can be used for the optimization of process. Temperature & catalysts role is explained in the process optimization topic given below.

Process Optimization:-

Process optimization is done in multiple ways.

1. Oil & wax is getting separated through the cyclones & the series of condensers. The series of condensers plays a vary vital role in the removal of oil in maximum quantity from the vapor from reactor. For 2.5 ton pyrolysis setup, as per experimentation, 2 condensers in series can give maximum output. [KEPL et al., 2016].
2. Regulation of the catalyst composition & temperature can optimize the process output & can be explained from the below given case studies of actual experimentation.

For all the below given three batches, the material used is the combination of PP, LDPE & PE type plastic of last life cycle stage so the carbon content in the same is higher with respect to the theoretical one.

Batch 1:-
Catalyst used – 0.002%
Feed of the process:- 700Kg

Time	09.00 am	09.30 am	10.00 am	10.30 am	11.00 am	11.30 am	12.00 am	12.30 pm	01.00 pm	01.30 pm	02.00 pm	02.30 pm
Reactor Temparature	330	335	338	342	345	349	350	353	364	375	382	390
Time	03.00 pm	03.30 pm	04.00 pm	04.30 pm	05.00 pm	05.30 pm	06.00 pm	06.30 pm				
Reactor Temparature	398	402	408	395	370	355	324	320				

Table 3 :- Batch 1 time & reactor temperature in deg. C.

Max. process temperature:- 402˚C
Output of the Process:-

Oil - 495Ltr. Avg Density - 0.78

Wax - 98 Ltr

Gas - 24 Kg.

Carbon - Approx - 175Kg

Batch 2:-
Catalyst used:- 0.002%
Feed of the process:- 700Kg

Time	09.00 am	09.30 am	10.00 am	10.30 am	11.00 am	11.30 am	12.00 am	12.30 pm	01.00 pm	01.30 pm	02.00 pm	02.30 pm
Reactor Temparature	332	338	340	345	355	360	365	368	370	378	385	395
Time	03.00 pm	03.30 pm	04.00 pm	04.30 pm	05.00 pm	05.30 pm	06.00 pm	6.3				
Reactor Temparature	405	420	402	385	374	359	343	330				

Table 4 :- Batch 2 time & reactor temperature in ˚C.

Max. process temperature:- 420˚C
Output of the Process:-

Oil - 540Ltr. Avg Density - 0.76

Wax - 105 Ltr

Gas - 32 Kg.

Carbon - Approx – 150Kg

Batch 3:-
Catalyst used:- 0.003%
Feed of the process:- 700Kg

Time	09.00 am	09.30 am	10.00 am	10.30 am	11.00 am	11.30 am	12.00 am	12.30 pm	01.00 pm	01.30 pm	02.00 pm	02.30 pm
Reactor Temperature	330	338	345	347	353	368	369	372	375	380	382	398
Time	03.00 pm	03.30 pm	04.00 pm	04.30 pm	05.00 pm	05.30 pm						
Reactor Temperature	421	412	398	377	356	332						

Table 5 :- Batch 3 time & reactor temperature in ˚C.
Max. process temperature:- 421˚C
Output of the Process:-

Oil - 545Ltr. Avg Density - 0.76

Wax - 108 Ltr

Gas - 30 Kg.

Carbon - Approx - 147Kg

All the above batches shows the continuous improvement in the output of the process that is in the efficiency. So can say that the with the change in the process parameters, process is getting optimized.

Results & Discussion

From Table 3 & Table 4, that is from the readings & results of the batch 1 & batch 2, its clear that the catalyst is kept constant, material, its composition & quantity is constant & the temperature of the process is increased.
This has improved the process output.

From Table 4 & Table 5, that is in the batch 2 & batch 3, catalyst is increased & the temperature is kept almost constant and the process output has been increased again as compared to the batch 2 & the process time has been reduced as compared with the batch 1 & batch2. This output is the maximum output in this composition of material under various experimentation of the catalyst & temperature conditions.

Thus we can say that, with the proper increase in the process temperature & catalyst amount, the process is getting more & more efficient, also with the proper amount of catalyst, the process time is getting reduced.

We got the optimum output & minimum process time for the PP & PE type of plastics on 421˚C process temperature & 0.003% of the catalyst in comparison with the raw material.

Conclusion

From the paper & experimentation results, it can be concluded that the pyrolysis process can be made optimum with particular amount of catalyst & particular process temperature. The process time can be reduced with the perfect amount of catalyst used in the process.

Temperature & catalyst in combine manner improves the process output & particular percentage of catalyst reduces process time with output improvement.

Appendix: Nomenclature

PP - Polypropylene
PE - Polyethylene
PS - Polystyrene
PVC - Polyvinyl Chloride
PET - Polyethylene Terephthalate
LDPE – Low density polyethylene.

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