Design and fabrication of fluidized cum fixed bed reactor for pyrolysis of WEEE

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***Abstract*- A preliminary study of pyrolysis of waste from electronic and electrical equipment carried out to understand pyrolysis behavior of certain WEEE's. TGA analysis carried out in order to find out optimum operating conditions and equilibrium conversion and yield at different conditions. Designed and fabricated a pyrolyser reactor which can be operated as fixed bed as well as fluidized bed reactor. Completed experimental set up using suitable condensers, utilities and exhaust system. This experimental setup should be helpful to carry out pyrolysis reactions at different operating conditions and find out yields.**

***Index Terms*- Fixed bed, fluidized bed, fuel oil, pyrolysis, WEEE.**

1. INTRODUCTION

Use of electrical and electronic equipment increasing worldwide day by day. Aggressive research and completion in market is reducing cost and increasing availability of such equipment every day. Average life of such equipment is decreasing due to this which is creating waste of electrical and electronic equipment (WEEE). Waste of electrical and electronic equipment (WEEE) made 5% of municipal solid waste (MSW) in 1997 and it expected to rose up to 10% by 2020 [9]. It showed annual growth of 7% from 2007 to 2012 [8].

WEEE's are composed of around 30.2% plastics, 30.2% refractory oxides and remaining 39.6% are metals. Metals such as copper, iron and tin make major part of metallic composition. Precious metals such as silver and gold are also found in WEEE. Plastic part of WEEE is composed of heavy polymers such as ABS, HIPS, PC, PP, PE, PVC, PBT etc. Plastic in WEEE is majorly divided into two types, viz. fire retardant (which makes 30% of plastic) and non-fire retardants (which makes 70% of plastic). Fire retardants plastic are further divided into halogenated and non-halogenated FR's (fire retardants). Halogenated FR's make 41% of FR's and considered toxic due to carcinogenic brominated compounds released during its decomposition. Non-halogenated FR's make 59% of FR's and are comparatively non-toxic [21].

Recycling of WEEE's has become difficult job due to their complex compositions which vary from source to source. Currently WEEE recycling is limited up to metal recovery only. Plastic part of WEEE which is potential source to hydrocarbon based fuels and different chemicals is being either incinerated or land filled. Land filling can intoxicate drinking water and may harm us unexpectedly in long run. Incineration releases toxic halogenated compounds in environment and it is waste of potential fuel.

In this research paper we wish to propose pyrolysis as solution to problem of recovery of WEEE's. In this paper we will discuss in details philosophy and designing strategy for development of fluidized cum fixed bed reactor and suitable set up for it which will facilitate pyrolysis of WEEE's to recover fuel oil.

2. DESIGN OF EXPERIMENTAL SET UP

In design part we will discuss in detail sample preparation methods and design philosophy behind development of fluidized cum fixed bed pyrolyser and other peripheral equipment.

2.1 Sample preparation

WEEE are very complex structure of metals, plastics and other non-organic, non-metallic materials used for its construction. Instead of trying out different

WEEE's, we will be using PCB's so that correlating effect of different parameters will be easier due to common source of feed material. PCB's having bulk density of around 1.7 gm/cc and manually cannot be cut below particle size of 3 to 4 mm. At such high bulk density and particle size nitrogen velocity required for fluidization would be very high. Providing such a high velocity may not be possible or viable.

Thus we acquired pre-prepared samples from external industry. Punjab based M/s Shiwalik solid waste management ltd. provided us finely grounded samples of PCB. These samples are almost free from metals and having bulk density of around 0.5 gm/cc. These samples came in two sizes: a) 300 to 500 µ and b) 100 to 300 µ. Because of low bulk density and comparatively lower particle size, required nitrogen velocity decreases which makes it practically feasible.

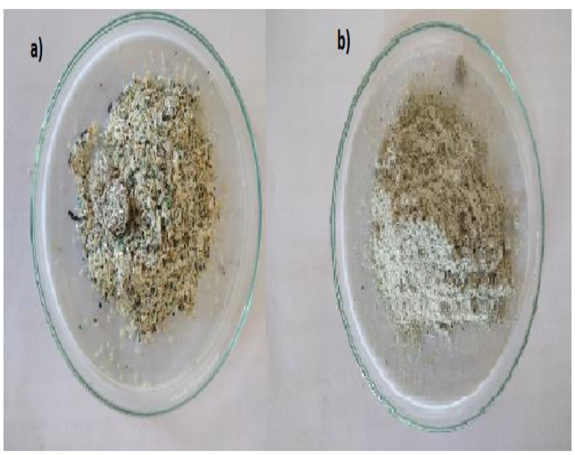

Figure 1 finely ground PCB samples: a) 300 to 500 µ, b) 100 to 300 µ

2.2 Reactor dimensions calculation

Basis of 200 gm of feed considered for calculating volume of feed. Following formula used for volume calculation.

$$Reactor\ volume\ (cm^3) = \frac{Feed\ capacity\ (gm)}{B.D.of\ feed\ (\frac{gm}{cc})} \quad (1)$$

Using above formula for feed size of 200 gm and having bulk density of 0.5 gm/cc, reactor volume works out to be 400 cm^3. Considering 6 times volume required for fluidization, reactor of total volume 2500 cm^3 developed. Interior part of reactor is specially designed to facilitate easy loading and removal of feed bed. Fig.2 shows schematic of pyrolyser.

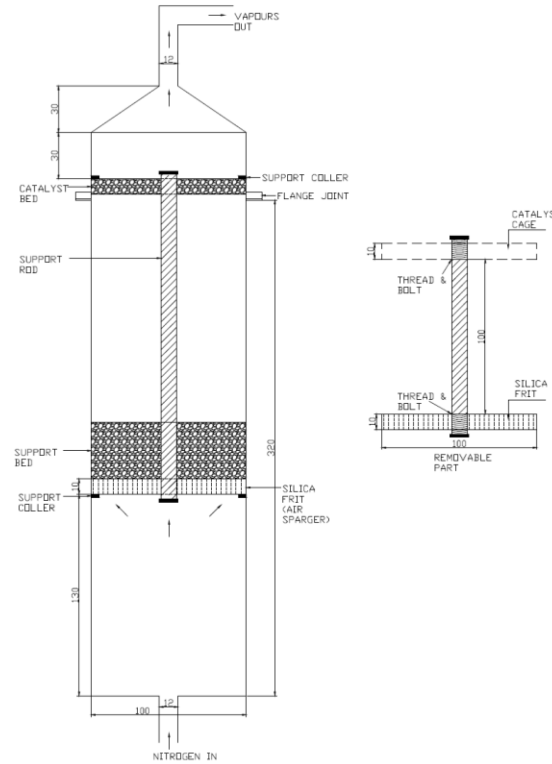

Figure 2 schematic of pyrolyser

2.3 Fluidization velocity calculation

Fluidization velocity can be calculated by using Kozeny-Carmen equation [15].

$$u_f = \frac{(\rho_p - \rho_f)\, g\, d_p^2 \varepsilon^3}{150\mu\,(1-\varepsilon)} \quad (2)$$

Minimum fluidization velocity can be obtained by

$$u_{mf} = \left[\frac{(\rho_p - \rho_f)\, g\, d_p \varepsilon^3_{mf}}{1.75\, \rho_f}\right]^{1/2} \quad (3)$$

Where,

µ = fluid viscosity (Nitrogen)	0.0000319 Pa.S (@400^{O}C)
ρ_f = Fluid density (Nitrogen)	1.251 kg/m^3
ϵ = Void fraction of bed,	0.75
u_f = fluid velocity	To be determined
d_p = Particle diameter.	300 ***µ***
ρ_f = Particle density	500 kg/m^3
ϵ_m =Minimum void fraction	0.2

Using above mentioned equations and available data, fluidization velocity found to be in range of 0.15 to 0.25 m/s while minimum fluidization velocity found to be 0.075 to 0.085 m/s.

2.4 Heat Load calculation

As reaction to be carried out at high temperature with fast heating rate, it is necessary to have a heater capable of delivering required heating rate and temperature. Heat duties of each head can be calculated with the help of following equation,

$$\Delta H = mC_p\Delta T \qquad (4)$$

Following are the major heat load heads those needs to be considered during designing heater.

Heat	Heat load head
Q1	Heat required to heat the Reactor
Q2	Heat required to heat the feed material
Q3	Heat required to heat of reaction (cracking)
Q4	Heat losses
Q5	Heat required to heat nitrogen flow

Available data for heat load calculation

Sample weight	0.25 kg
Specific heat of sample	1300 J/kg.K
T1	30 ^{O}C
T2	600 ^{O}C
Nitrogen volumetric flow	0.006 m^3/s
Nitrogen mass flow	0.007 kg/s
Specific heat of nitrogen	1040 J/kg.K (@300^{O}C)
Heat of reaction of sample	700000 J/kg
Mass of reactor	10 kg
Specific heat of SS-316	530 J/kg.K

We aim to achieve reaction temperature within 30 minutes. Thus heater having capacity sufficient enough to deliver heat load required. Using above formula and above data, heat load calculation is as follow

Heat	Heat load (J)	Power (W)
Q1	3450 kJ	2000 W
Q2	217 kJ	120 W
Q3	175 kJ	97 W
Q4	Assumed to be 20% of total	-
Q5	2520 kJ	1400 W

As per above calculations total power requirement without considering heat losses is 3600 W. Hence we have provided heater of capacity 6 kW to the reactor.

3. RESULTS AND DISCUSSION

As seen in fig.3, reactor is made up of cylindrical shell of SS-316, having diameter 100 mm, height 320 mm and thickness 7 mm. Reactor top is semispherical cover designed to collect and guide vapors out of the reactor. From bottom of the reactor provision is provided for nitrogen to enter the reactor and facilitate fluidization. Internal part of reactor is developed as removable part in order to facilitate frequent cleaning and maintenance. It consists of threaded rod of 10 mm diameter over which spherical screens can be arranged to make provision for product bed and catalyst bed. At top and bottom of cylindrical shell, support collar is provided to support removable part of reactor. Screen size used for air distribution is 100 $\boldsymbol{\mu}$ or 150 BSS. This screen is supported by bottom screen of higher size, having higher thickness. Two or three screens can be arranged on threaded screw to provide support for sample and catalyst beds.

In addition to above reactor, nitrogen cylinder with regulator is provided to regulate nitrogen flow rate to reactor. Series of condensers provided after reactor to condense vapours formed during pyrolysis and convert it into fuel oil. Flat bottom flat is provided for oil recovery.

Figure 3 Experimental set up

4. CONCLUSION

With the help of literature we were able to identify general operational parameters such as temperature, heating rate, time etc. required for pyrolysis catalysis of WEEE. Using chemical engineering techniques fluidized catalytic pyrolyser designed and fabricated. Additional equipments such as heater, condensers, PLC controllers, nitrogen cylinder with regulator arranged. Completed experimental setup and arranged samples for pyrolysis.

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An acknowledgement section may be presented after the conclusion, if desired.

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