

## Refuse Derived Fuel Generation



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### **Abstract:**

Due to the increase in generation, waste plastics are becoming a major stream in solid waste. After food waste and paper waste, plastic waste is the major constitute of municipal and industrial waste in cities. Even the cities with low economic growth have started producing more plastic waste due to plastic packaging, plastic shopping bags, PET bottles and other goods/appliances using plastic as the major component. This increase has turned into a major challenge for local authorities, responsible for solid waste management and sanitation. Due to lack of waste recycling could also be economically viable, as it generates resources, which integrated solid waste management, most of the plastic waste is neither collected properly nor disposed of in appropriate manner to avoid its negative impacts on environment and public health and waste plastics are causing littering and choking of sewerage system.

### **I. INTRODUCTION**

Plastic is the general common term for a wide range of synthetic or semi-synthetic organic amorphous solid materials used in the manufacture of Industrial products. Plastics are typically polymers of high molecular mass, and may contain other substances to improve performance and/or reduce costs. The common word plastic should not be confused with the technical adjective plastic, which is applied to any material which undergoes a permanent change of shape (plastic deformation) when strained beyond a certain point. Aluminum, for instance, is plastic in this sense, but not a plastic in the common sense. In contrast, in their finished forms, some plastics will break before deforming and therefore are not plastic in the technical sense. There are two main types of plastics: Thermoplastics and Thermosetting Polymers. Thermoplastics can repeatedly soften and melt if enough heat is applied and hardened on cooling, so that they can be made into new plastics products.

Examples are polyethylene, polystyrene and polyvinyl chloride, among others. Thermosets or thermosetting can melt and take shape only once. They are not suitable for repeated heat treatments; therefore after they have solidified, they stay solid. Examples are phenol formaldehyde and urea formaldehyde. Plastics can also be classified by various physical properties, such as density, tensile strength, glass transition temperature, and resistance to various chemical products. Due to their relatively low cost, ease of manufacture, versatility, and imperviousness to water, plastics are used in an enormous and expanding range of products, from paper clips to spaceships. They have already displaced many traditional materials, such as wood, stone, horn and bone, leather, paper, metal, glass, and ceramic, in most of their former uses.

## II. Methods to Convert Plastic Wastes into Fuel

There are two methods to convert plastic wastes into fuel, they are

- Pyrolysis.
- Random De-Polymerization.

### Pyrolysis

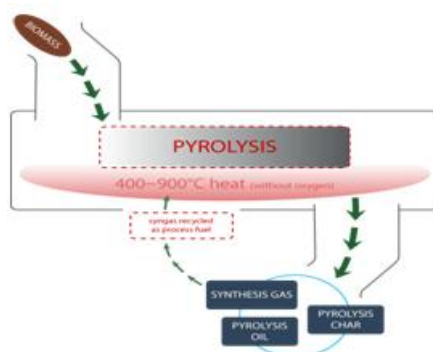


Fig 1: Pyrolysis process

Pyrolysis is a process of thermal degradation in the absence of oxygen. 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-420°C and the pyrolysis gases are condensed through a distillation tower to produce the distillate.

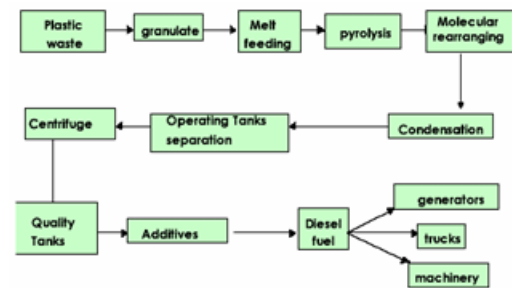


Fig 2: Steps involved in conversion

The heart of the pyrolysis system is the prime chamber, which performs the essential functions of homogenization, controlled decomposition and outgassing in a single process.



Fig 3: Types of crude oils obtained after operation Random de-polymerization

All plastics are polymers mostly containing carbon and hydrogen and few other elements like chlorine, nitrogen, etc. Polymers are made up of small molecules, called monomers, which combine together and form large molecules, called polymers. When these long chains of polymers break at certain points, or when lower molecular weight fractions are formed, this is termed as degradation of polymers. This is reverse of polymerization or de-polymerization. If such breaking of long polymeric chain or scission of bonds occurs randomly, it is called 'Random de-

polymerization'. Here the polymer degrades to lower molecular fragments.

### The Process of Conversion

Under controlled reaction conditions, plastic materials undergo random de-polymerization and are converted into three products:

- a) Solid Fuel – Coke
- b) Liquid Fuel – Combination of Gasoline, Kerosene, Diesel and Lube Oil
- c) Gaseous Fuel – LPG range gas.

The process consists of two steps:

- 1) Random de-polymerization - Loading of waste plastics into the reactor along with the Catalyst system. Random de-polymerization of the waste plastics.
- 2) Fractional Distillation - Separation of various liquid fuels by virtue of the difference in their boiling points.
- 3)

One important factor of the quality of the liquid fuel is that the sulphur content is less than 0.002 ppm – which is much lower than the level found in regular fuel.

In the process of conversion of waste plastics into fuels, random de-polymerization is carried out in a specially designed reactor in the absence of oxygen and in the presence of coal and certain catalytic additives. The maximum reaction temperature is 350°C. There is total conversion of waste plastics into value-added fuel products.

**Table 2: Fuel Conversion volume in %**

FUEL TYPE	CONVERSION VOLUME IN %
Solid fuel (Coke)	5-7
Liquid fuel (collected after condensation)	70-80
Gaseous fuel (LPG)	15-20

### III. Analysis on Plastic Pyrolysis

#### Factors affecting Plastic pyrolysis

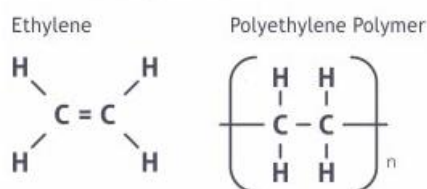
The major factors influencing the plastic pyrolysis process and pyrolysis product molecular distribution include chemical composition of the feedstock, cracking temperature and heating rate, operation pressure, reactor type, residence time and application

of catalyst. These factors are summarized in this section as follows.

### Chemical composition of feedstock

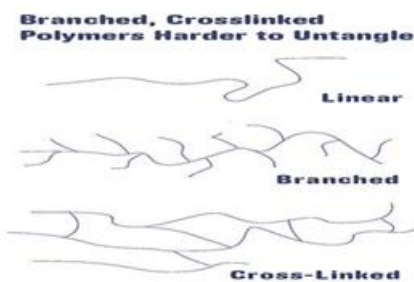
The pyrolysis products are directly related to the chemical composition and chemical structure of the plastics to be pyrolyzed. In addition, the chemical composition of the feedstock also affects the pyrolysis processes. In reality, waste plastics are possibly contaminated before recycling which could also have effects on the pyrolysis process and products.

Chemical composition of PE:



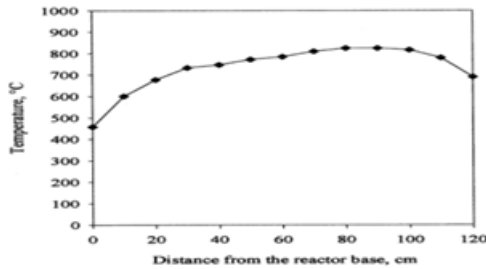
**Fig 4: Polymerization of ethylene to polyethylene**

Plastics can be classified, according to structural shape of polymer molecules, as linear, branched, or cross-linked. The units in linear polymer are linked only to two others, one to each ends. The polymer is termed branched when branches extend beyond the main polymer chain randomly.



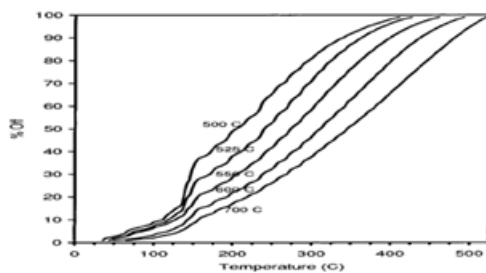
**Fig 5: Polymer structure, linear, branched and cross linked**

A cross linked polymer can be described as an interconnected branched polymer with all polymer chains are linked to form a large molecule. Thus, the cross linked polymer constitutes large molecule. Theoretically, the molecular weight of a cross linked polymer can be infinite.

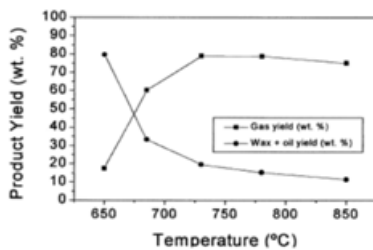


**Fig 6: Temperature profile along the tube reactor**

Fig 7 shows the Gas Chromatography (GC) analysis results of the liquid products with the temperature on the curves indicating the cracking temperature. It is seen that the liquids produced at higher cracking temperatures have lower flash-off percentage at the same GC temperature during the analysis.



**Fig 7: GC analysis results of plastic pyrolysis liquid**



**Fig 8: Influence of temperature on product distribution**

However, the overall gas proportion of gas product increased with increasing cracking temperature up to 730 C while the liquid product proportion decreased with the cracking temperature in the full range of temperature used.

### Residence Time

The definition of residence time differs in various studies. In fast pyrolysis or continuous pyrolysis process, it refers to the contact time of the plastic on the hot surface throughout the reactor. However in slow pyrolysis and batch process, the residence time means the duration from the time when feedstock plastic start to be heated to the time when the products are removed. In a slow pyrolysis, long residence time encourages the carbonization process and produces more tar and char in the products. The pyrolysis conditions, residence time and target products are given in Table 3.

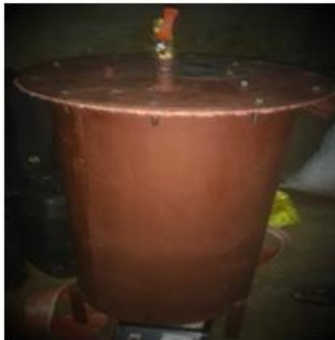
Process	Heating rate	Residence time	Temperature ( C )	Target products
Slow carbonization	Very low	days	450-600	Charcoal
Slow pyrolysis	10-100K/min	10-60 min	450-600	Gas, oil, char
Fast pyrolysis	Up to 1000K/s	0.5-5s	550-650	Gas, oil, (char)
Flash pyrolysis	Up to 10000 K/s	<1s	450-900	Gas, oil, (char)

**Table 3: Pyrolysis process and target products**

### IV. Description of the Equipment

#### Pressure vessel

This is an insulated mild steel cylindrical reactor heated by electrical heating coils to achieve a maximum heating temperature of 500 C. The necessary provision is made on the reactor for mounting the gadget like pressure gauge for measuring pressure, and collection of hydrocarbons from the reactor.



**Fig 9: Pressure vessel**

### Design calculations of pressure vessel

It is done on the basis of two stresses

1. Circumferential (or) tangential stress ( $\sigma_t = \frac{P_i D_i}{2t}$ ) it is also referred as hoop stresses.

2. Longitudinal stress ( $\sigma_l = \frac{D_i P_i}{4t}$ ).

$$\sigma = \frac{S_{ut}}{F_s}$$

Material used is Mild steel (AISI 1018)

$P_i$  = inlet pressure

$D_i$  = inlet diameter

$t$  = thickness of pressure vessel

$\sigma$  = stress

$S_{ut}$  = Ultimate tensile strength of mild steel (i.e 460 mpa)

$F_s$  = Factor of safety (i.e 1)

Known values are as follows

Diameter of vessel = 400mm

Thickness of vessel = 6mm

Height of vessel = 925mm

Consideration for design

1) Circumferential (or) tangential stress

Where  $\sigma = 460$  (using design data hand book)

$$P_1 = (2t)(\sigma) / d = (2 \times 6)(460) / 400 = 13.8 \text{ N/mm}^2 = 140.7186 \text{ Kg/cm}^2$$

2) Longitudinal stress

$$P_2 = (\sigma)(4t) / d = (460)(4 \times 6) / 400 = 27.6 \text{ N/mm}^2 = P_2 = 281.4372 \text{ Kg/cm}^2$$

### Helical Coil Heat Exchanger

A heat exchanger is the process to transfer heat from one fluid to another fluid.

The heat exchanger is devise that used for transfer of internal thermal energy between two or more fluids at different temperatures. In most heat exchangers, the fluids are separated by a heat transfer surface, and ideally they do not mix. Heat exchangers are used in the process, power, petroleum, transportation, air conditioning, refrigeration, Cryogenic, heat recovery, alternate fuels, and other industries. Common examples of heat exchangers familiar to us in day-to-day use are automobile radiators, condensers, evaporators, and oil coolers.

### Features of helical coil heat exchanger

- Optimal design for corrosive fluid.
- High flow in a small path.
- Highly resistant to thermal and hydraulic shock.
- Bolted or all welded shell.
- Numerous flow path and connection configurations.
- Compact and lightweight.
- Easy to install.
- Pressure drop of one fluid is limited.

### Design methodology

Determine the heat-transfer coefficients: To calculate the heat-transfer coefficients in the coil and the annulus, the following parameters must be known

1) The length of coil,  $L$ , needed to make  $N$  turns:  

$$L = N \sqrt{((2\pi r)^2 + p^2)} \quad (1)$$

2) The volume occupied by the coil,  $V_c$   

$$V_c = (\pi/4) \times (D_o)^2 \times L \quad (2)$$

3) The volume of the annulus,  $V_a$

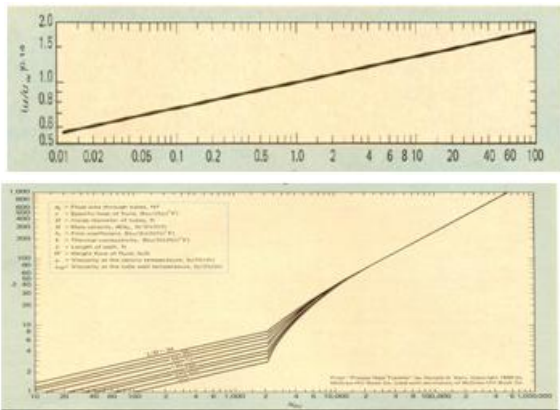
$$V_a = (\pi/4) \times (C^2 - B^2) \times p \times N \quad (3)$$

4) The volume available for the flow of fluid in the annulus,  $V_f$

$$V_f = V_a - V_c \quad (4)$$

5) The shell-side equivalent diameter of the coiled tube,  $D_e$

$$D_e = (4 \times V_f) / (\pi \times D_o \times L) \quad (5)$$



**Fig 10: Colburn factor vs Reynolds number for tube-side heat transfer**

The heat transfer coefficient in the annulus,  $h_o$ , can now be calculated using one of the following equations. For Reynolds numbers,  $N_{RE}$ , in the range of 50-10,000, Eq.6[3] is recommended:

$$h_o D_o / k = 0.6 * (N_{RE}^{0.5}) * (N_{PR}^{0.31}) \quad (6)$$

For  $N_{RE}$  over 10,000, Eq. 7 [4] should be used

$$h_o D_o / k = 0.6 * (N_{RE}^{0.5}) * (N_{PR})^{1/3} * (\mu / \mu_w)^{0.14} \quad (7)$$

The heat transfer coefficient of the fluid flowing inside the coil,  $h_{io}$ , can be determined using conventional methods, such as described in Ref. [4]. The heat transfer coefficient based on the inside coil diameter,  $h_i$  is obtained using a method for a straight tube-either one of the Sieder-tate relationships, or a plot of the Colburn factor,  $J_H$ , vs.  $N_{RE}$ , such as Fig.3 That must then be corrected for a coiled tube by multiplying  $h_i$  by  $[1 + 3.5(D/D_H)] - [5]$  to get  $h_{ic}$ . The coefficient based on the outside diameter of the coil,  $h_{io}$ , is then obtained by

$$h_{io} = h_{ic} (D/D_o) \quad (8)$$

The overall heat-transfer coefficient,  $U$ , is given by

$$1/U = 1/h_o + 1/h_{io} + x/k_c + R_t + R_a \quad (9)$$

### To determine the required area

The area needed for the heat transfer is determined by

$$A = Q / U * \Delta t_c \quad (10)$$

The log-mean-temperature-difference,  $\Delta t_{lm}$ , must be corrected to take into account the fact that the fluids are flowing perpendicular to each other, which is done by applying the standard correction factor for perpendicular flow.

### Determine the number of turns of coil

Since  $A = \pi * D_o * L$ , and  $L$  is expressed in terms of  $N$ , the number turns of coil needed can be calculated by

$$N = A / (\pi * D_o * (L/N))$$

The actual number of coil turns needed,  $n$ , is simply  $N$  rounded to the next highest integer.

Liquid A flows inside a copper pipe coil. Liquid B in the annulus. The flow-rates, the inlet and outlet temperatures, and the physical properties of the fluids are given in table

PROPERTY	LIQUID A	LIQUID B
MASS FLOWRATE, M, Kg/h	60	500
Inlet temperature, °C	127	30
Outlet temperature, °C	100	47
Heat capacity, $C_p$ , kcal/(kg)(°C)	1.00	1.00
Thermal capacity, $k$ , kcal/h(m)(°C)	0.419	0.4075
Viscosity $\mu$ , kg/(m)(h)	1.89	5.76
Density, $\beta$ , kg/m <sup>3</sup>	870.0	935.0

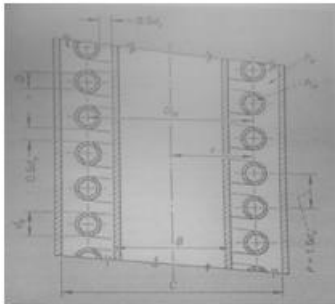
**Table 4: Flow rates and properties of liquid**

Where  $D = 0.019m$ ,  $d_o = 0.020m$ ,

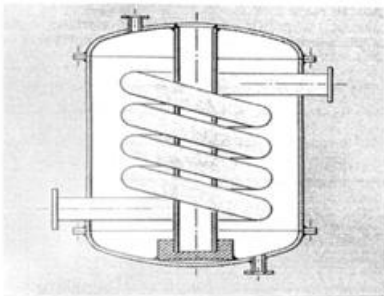
$B = 0.340m$ ,  $C = 0.460m$ ,  $D_H = B + 2D = 0.380m$ , pitch  $(p) = 1.5 * d_o = 0.0285m$ .



**Fig.8.2 Helical coil Heat exchanger with casing**



**Fig.8.3 Schematic cutaway view of an HCHE**



**Fig.8.4 A helical coil heat exchanger**

**To calculate the shell side heat transfer coefficient,  $h_o$ .**

From Eq. (1), the length of coil needed is

$$L = 1.0057N \text{ meter}$$

Using equation 2-4, the volume available for fluid flow in the annulus,  $V_F$ , is

$$V_F = 1.863 \times 10^{-3} \times N$$

The shell side equivalent diameter using Eq.5 is

$$D_e = 0.124 \text{ m}$$

The mass velocity of the fluid is

$$G_s = M / (\pi/4) ((C^2 - B^2) - (D_{H1}^2 - D_{H2}^2))$$

Here,

$$D_{H1} = 0.38 + 0.019 = 0.399 \text{ m} \quad \& \quad D_{H2} = 0.361 - 0.19 = 0.342 \text{ m}.$$

Hence by substituting all the required values we have,

$$G_s = 11833.08 \text{ kg/m}^2\text{h}.$$

The Reynolds number is

$$N_{RE} = (Du\beta / \mu)$$

$$N_{RE} = (0.124)(11833.08) / 5.76 = 255.$$

Using Eq.(6), we get

$$h_o = (0.6) (255)^{0.5} (1/5.76/0.4075)^{0.31}$$

$$h_o = 71.567.$$

**Compute  $h_{io}$ , the heat transfer coefficient inside the coil.**

The fluid velocity is

$$u = q / A_f$$

$$q = M / \beta = 500 / 935 = 0.534, \text{ and } A_f = \pi D^2 / 4 = 2.835 \times 10^{-4} \text{ m}^2.$$

Hence,

$$u = 1883.59 \text{ m/h}.$$

The Reynolds number (tube-side) is then

$$N_{RE} = (Du\beta) / (\mu).$$

$$N_{RE} = 16473.93$$

From fig.2,  $J_H$  (For  $N_{RE} = 16473.93$ ) is 40, and

$$h_i = J_H (k / D) (N_{PR})^{1/3}$$

$$h_i = 2026.1225 \text{ kcal / (h)(m}^2\text{)(}^\circ\text{C)}.$$

Corrected for a coiled tube, this becomes

$$h_{ic} = 2026.1255 [1 + 3.5(0.019/0.020)]$$

From Ref.5

$$h_{ic} = 2381 \text{ kcal / (h)(m}^2\text{)(}^\circ\text{C)}.$$

The heat transfer coefficient based on the outside diameter of coil from Eq.8 is

$$h_{io} = 2261.95 \text{ kcal / (h)(m}^2\text{)(}^\circ\text{C)}.$$

**Calculate the overall heat transfer coefficient,  $U$ .**

The coil wall thickness,  $x$ , is

$$x = (d_o - D) / 2.$$

$$x = 5 \times 10^{-4} \text{ m}.$$

The fouling factors,  $R_f$  and  $R_a$ , depend on the nature of the liquids, the presence of any suspended matter in the liquids, the operating temperatures and the velocities of the fluids. In this case, both  $R_f$  and  $R_a$  are  $8.2 \times 10^{-4} \text{ kcal/(h)(m}^2\text{)(}^\circ\text{C)}$ .

Using Eq.9

$$1/U = 1 / 71.56 + 1 / 2262 + (5 \times 10^{-4}) / 344 + 0.00082 + 0.00082.$$

$$U = 62.60 \text{ kcal/(h)(m}^2\text{)(}^\circ\text{C)}.$$

**Determine the required area**

The log-mean-temperature-difference is

$$\Delta t_{lm} = [(127-30)-(100-47)] / \ln [(127-30)-(100-47)]$$

$$\Delta t_{lm} = 72.8 \text{ }^\circ\text{C}.$$

To account for perpendicular flow, the correction factor[6] is 0.99, so that

$$\Delta t_c = 0.99 * 72.8 = 72.1 \text{ }^\circ\text{C}.$$

The heat load is

$$Q = (M_A \times C_p \times \Delta t)$$

$$Q = 1625.65, \text{ since } C_p = 1.00, M_A = 60$$

kg/h.

Using Eq.10, the required area is

$$A = (1625.65) / (62.60 \times 72.1)$$

$$A = 0.36018 \text{ m}^2.$$

### To calculate the number of turns of coil required

From Eq.11

$$N = (0.36018) / (\pi)(0.020)(1.0057)$$

$$N = 5.699$$

we can round it off to  $N = 6$  turns.

The height of the cylinder needed to accommodate 6 turns of coil is

$$H = N * p + d_o.$$

$$H = (6)(0.0285) + (0.020) \quad H = 0.0191$$

m.

### Receiver

The condensed hydrocarbon in the liquid form is collected in the receiver. The provision is made for collecting the uncondensed gases in to gas collector. Therefore the obtained liquid is in the form of a crude oil.

### V. Unique Features of the Process

- All types of plastics waste including CD's and floppies having metal inserts, laminated plastics can be used in the process without any cleaning operation. Inputs should be dry.
- Bio-medical plastics waste can be used.
- About 1 liter of fuel is produced from 1 kg of plastics waste. By-products are coke and LPG Gaseous Fuel.
- Any possible dioxin formation is ruled out during the reaction involving PPVC
- Waste, due to the fact that the reaction is carried out in absence of oxygen, a prime requirement for dioxin formation.
- This is a unique process in which 100% waste is converted into 100% value-added products.

- The process does not create any pollution.

### Advantages

- Reduces pollution helps in waste plastic degradation.
- Cheaper and quality fuel.
- Perfect solution for waste plastic, rubber, tire management.
- Raw material readily available.
- Plant is energy self-sufficient.

### Disadvantages

- Smoke is high compare to other fuels
- More heat generation is required
- More attention is required to maintain pressure

### Applications

The products obtained by this process have been tested at IOC (R&D) and end uses, are as follows:

### End uses for liquid hydrocarbon

- a) D.G Sets for Generation of Electricity.
- b) Fuel for Agricultural pumps.
- c) Fuel for Boiler.
- d) Marine Fuel (Bunker fuel).
- e) As input feed for Petroleum Refineries.
- f) Fuel oil etc.

### End uses for Gas

- a) Any nearby industries using LPG.
- b) For in-house consumption.

### For solid fuel

- a) Thermal power plants.
- b) Metallurgical Industries.

### VI. CONCLUSION:

Thermo fuel 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.



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