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The Science of Second Chances: Giving Plastic a New Life Through Pyrolysis

Introduction:

In today's world, plastic is omnipresent due to many good qualities of it such as its cost effectiveness, ease of making products in practically any size, colour and shape. Also, it can be very easily manufactured in bulk to meet the ever-increasing demand of plastic products. Plastic, due to its various properties, can be found in factories making products for human consumption (that is food safe plastic) to one time use plastic bags.

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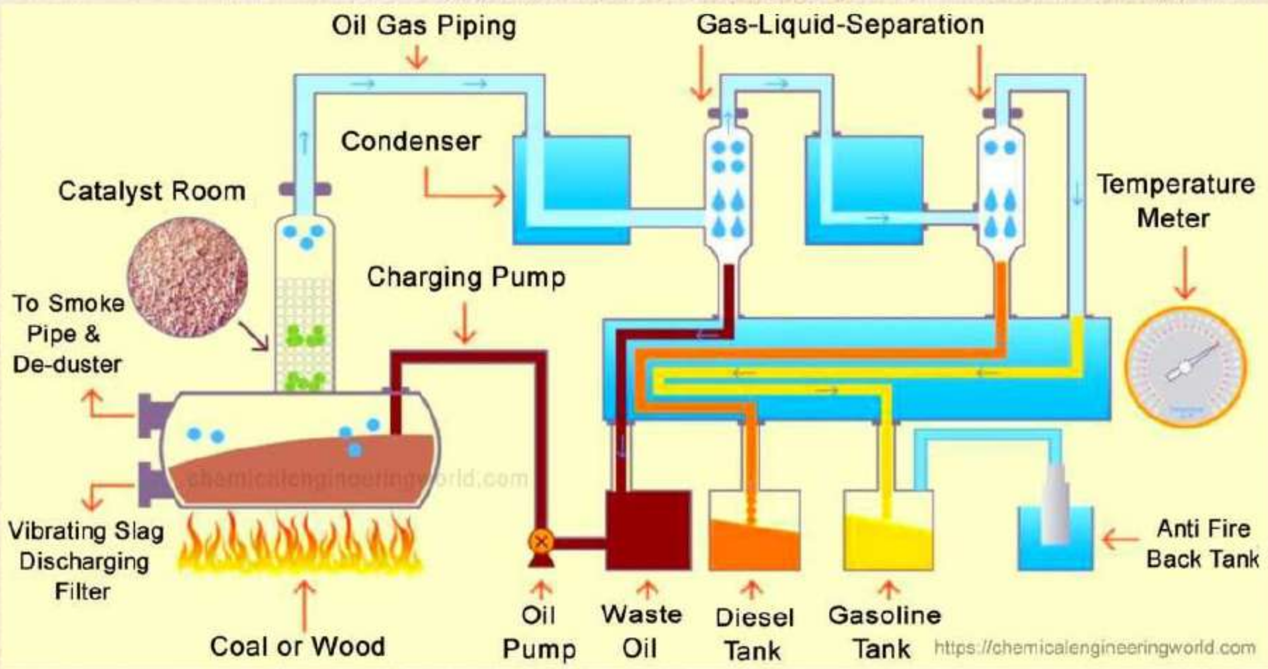
So, researchers and scientists across the globe were and are searching for various methods to recycle plastic and rubber waste, such as reuse of some plastic waste with virgin plastic to make plastic goods, using plastic waste along with asphalt to make roads, etc. There is another way by which we can recycle the plastic and reduce the pollution caused by plastic which is called as Pyrolysis and we would understand about this process over here. Pyrolysis isn't a new technique as it is known to the mankind for ages and in the past, human beings used Pyrolysis technique for converting wood into charcoal and tar.

What is Pyrolysis:

Pyrolysis is a process in which materials like biomass (such as wood chips, saw dust, stubbles, etc.), plastics waste or tires are put into a big drum like vessel. This vessel is heated by hot gases created initially by burning coal / furnace oil. Due to this heat, the waste plastic or tyres inside the vessel would first start melting. At the desired temperature (depending upon raw materials used and quality of output oil required, it ranges from 2000C to 9000C) in the presence of catalysts and absence of Oxygen, the complex molecules of wood, plastic, rubber tyres, etc. would start breaking down into simple molecules of:

- Combustible Gas which is called as syngas
- Liquid which is called bio-oil / pyrolysis oil (Petrol, Diesel and Heavy oil can be obtained from it after further refining) and
- Solid char / Black residue which is called as biochar.



These molecules which in the form of high temperature vapours in the vessel are taken out using a pipe to a condenser where those vapours are cooled and various above items (except for the char) are collected separately. Char is the residue which remains in the vessel and is removed directly from the vessel. This whole process is pictorially seen as shown above.

As we are using farm stubbles, plastic waste, waste rubber tyres, oil sludge from refineries, spills, and tank bottoms, along with sewage or animal wastes as a raw material in this process, it is a sustainable waste-to-energy process that turns waste into valuable products, reduces landfill burden, pollution due to burning of stubbles and creates alternatives to fossil fuels. So, let us understand about this process in more detail and how it can be helpful for reducing the plastic waste and improve the life on this planet Earth. PVC and PET is avoided as it creates toxic emissions.

Raw Materials Used for Pyrolysis:

Following raw materials are used in Pyrolysis. In order to get better results, the raw material should be cut into pieces of smaller and similar sizes, there should not be much variation in the size of raw material used otherwise the output may not be consistent and optimal.

Biomass Materials: It covers high lignin content materials such as wood waste, sawmill residues and forest debris. Non-food-competing feedstocks and agricultural residues like straw, stubbles and rice hulls. Municipal solid waste and invasive plants also serve as viable options. Its energy density of wood waste is generally between 3.5 to 5.5 Mega Jules/Normal Cubic Meters (MJ/Nm3). The yields of biomass vary depending upon the pyrolysis process adopted. However, typically for fast pyrolysis (>100C / Sec), we can get 60-75% bio-oil, 15-25% bio-char and 10-15% gas. In slow Pyrolysis process, we can get 35-50% bio-char, 20-30% liquid and 25-35% gas.

Plastics: Suitable plastics encompass HDPE, LDPE, PP, PS, and PC, which break down into oils effectively. Their energy density is generally between 30 to 40 MJ/Nm3. Generally, PVC is avoided in Pyrolysis process as it produces high Hydrogen Chloride (HCl). In case of PET getting used as a raw material, it creates acidic compounds which pose a major challenge to dispose off, being avoided for Pyrolysis process.

Rubber Tyres: Waste rubber tires, having energy density of about 30 to 40 MJ/Nm3 can yield 30-52% oil and most importantly, it addresses disposal challenges of waste rubber tyres. So, waste tyres can be used as raw material for pyrolysis or can also be used as medium to generate heat (i.e., waste tyres can be burned to heat the pyrolysis tanks).

Other Feedstocks: Oil sludge from refineries and spills recovers hydrocarbons. Sewage, animal wastes, and high-lignin items like nut shells or burned trees suit co-processing. Since in this raw material, lots of variety is there, depending upon the raw material used, we cannot define the output.

Details of Pyrolysis Process:

In Pyrolysis processes the raw materials are heated in a drum in the absence of oxygen (so that they should not burn or oxidise). To remove oxygen from the drum in a cost-effective way, mostly Nitrogen is used as a medium. So, generally, pyrolysis plants have their own Nitrogen extraction units (from atmospheric air). The initial heating is carried out by burning furnace oil or similar low-cost organic matter which can give heat at cost effective rates. To optimise the pyrolysis process, the drum is kept horizontal and rotated around the horizontal axis using some external mechanism, so that all the raw material is heated evenly and the output is better controlled. Inside the drum, the flue gases pass around the raw material through tubes so that the heat transfer takes place around the tubes or sometimes the bottom part of the drum is heated using the flue gases. To improve the process efficiency, the flue gases may heat the raw material before it enters into the drum. Once the raw material is heated to the desired temperature, in the presence of catalysts (depending upon the raw materials), the raw material breaks down from complex organic chains to simple organic materials, and try to escape in the form of gases.

These gases are collected and passed through different sets of condensers serially to cool them down at various temperatures and the cooled down gases at various temperature are converted into pyrolysis oil of different chemical and physical properties.

The gases which cannot be cooled down at normal room temperature are collected in gas balloon and are used to heat the raw materials in the Pyrolysis process to reduce the input costs.

The residue which remains in the drum is collected and called as Char or Biochar. Depending upon the raw material used, it may contain ash, different metallic substances (in case of tyres used as raw materials).

This heating process could be either batch type or continuous type. In batch-type pyrolysis process, as the name suggests, a batch of raw material is heated and outputs are collected. In case of continuous process, the raw materials are continuously fed from one side of a drum and output char / biochar is continuously getting collected from the other end of the drum. Following comparison statement gives various aspects of batch and continuous Pyrolysis process:

Parameter	Pyrolysis Batch Process	Pyrolysis Continuous Process
Processing Capacity	It is ideal for small to medium-scale operations, typically processing 10 kg to 15 tons per day	It is suitable for large-scale industrial projects with a high daily capacity, generally ranging from 15 to 50 tons or more
Raw Materials Characteristics	If offers greater flexibility and can handle varied or heterogeneous waste streams, including whole tires, without extensive pre-treatment	It requires uniform, consistently sized feedstock (e.g., rubber powder or small plastic pieces) and needs additional pre-processing equipment like shredders and wire-drawing machines.
Capital and Operational Costs	It has a lower initial capital investment due to simpler design and less automation. However, it incurs higher labour costs and energy consumption per unit of output due to repeated heating and cooling cycles.	It involves a higher initial investment for complex, automated systems. It provides lower long-term labour costs and improved energy efficiency because it runs uninterruptedly
Automation Level and Labour	It is semi-automatic and requires more manual labour (around 3-4 workers per shift) for tasks like loading and unloading	It utilizes PLC automated intelligent control systems, requiring less labour (1-2 people) for the entire production line
Product Quality	The product quality (oil, carbon black) may be inconsistent due to the cyclic heating and cooling and variations in material loading	It ensures a stable and consistent product quality due to the steady, controlled process environment
Environmental Considerations and Safety	It typically involves open-type slag discharge, which may have lower safety and environmental protection coefficients.	It features a fully automatic closed feeding and discharge system, enhancing safety and environmental performance by preventing pollution from contacting the atmosphere

Output from Pyrolysis:

When we carry out pyrolysis process of the above raw material, as stated above we mainly get three forms of output that is solid, liquid and gas. Let's discuss them in details.

Syngas: Combustible Gas produced using Pyrolysis process is called as Syngas. It is a mixture of hydrogen, carbon monoxide, methane, etc. hydro-carbons. Following table roughly gives details of Syngas produced.

Raw Material or Feedstock	Primary Gas Components	Critical Contaminants
Wood Chips	H_2, CO, CH_4, CO_2	High Tar & Moisture
Plastics	C_1-C_4 Hydrocarbons, H_2	HCl (from PVC), H_2S
Rubber Tyres	H_2, CO, CH_4, C_2H_4	Sulphur, Zinc, H_2S
Oil Spills	Alkanes, Alkenes, H_2	Heavy Metals, Brine/Salt

Pyrolysis Oil: Pyrolysis oil is a complex liquid fuel containing water, many organic compounds, and often some solids, and its exact composition depends strongly on the feedstock (biomass, plastic, tires, etc.) and operating conditions such a temperature.

- **Low Temperatures (400-500°C):** When pyrolysis is carried out at lower temperature range, oil from plastics like HDPE yields high liquid volumes (up to 40% from HDPE), with densities around 0.67-0.74 kg/L and viscosities of 3-4 Centistokes (cSt), dominated by aliphatic hydrocarbons (C6-C19 fractions like gasoline, kerosene, diesel after distillation). Biomass oils show higher water-insoluble compounds and molecular weights. Tire oils contain more limonene (3.1 wt%) and aliphatics.

- **Medium Temperatures (450-550°C):** At medium temperature, yields peak for many feedstocks, with oils featuring balanced aliphatic oils and emerging aromatics like benzene, toluene, and styrene; flash points of these oils rise to 42-55°C due to less volatiles. Aromatic content increases slightly, Polycyclic Aromatic Hydrocarbon (PAH) from 1.5 wt%, and oxygenated phenolic (e.g., guaiacol / 2-methoxyphenol, cresol) persist in biomass-derived oils.

- **High Temperatures (550-700°C+):** Above 550°C, aliphatic content drops sharply, aromatics and PAH rise to 3.5 wt%, with more gases and char; oils become lighter with higher flash points but lower yields. Molecular weight and viscosity decrease at 580°C+ from cracking.

Solids or Biochar: It can also be called as Carbon Black, containing about 50-80% carbon about 1-5% hydrogen and other trace elements. It can also contain about 3-30% ash and it is neutral to alkaline (pH range 7-11). There are two types of solids which can be generated; one is when we use biomass materials. In this case the biochar can be used to mix it with fertile soil to increase its carbon content to make it better yield soil or can be used to make activated carbon or tyre filler. In case if Plastic or Rubber Tyres are used as raw materials, since their chemicals are mixed in plastic and rubber tyres in their manufacturing process, this biochar is used for industrial applications not related to human or animal food chains such as using as tyre filler, etc.

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Summary:

As the menace of pollution from plastic, rubber, etc. is increasing, scientists have been working effortlessly to find ways to reduce this pollution and they stumbled upon the ancient technique of wood Pyrolysis which they repurposed for plastic, rubber tyres, etc. People have started using this technique to convert the polluting items into useful energy and over a period of time this process would be more refined to be more efficient and causing very less harm to the environment. Considering the advantages of Pyrolysis, it can be seen as one of the answers to the pollution monster thereby preserving the earth for future generations.