Analysis of Waste Tyre Recycling Processes for Improvement of Environmental Sustainability and Feasibility

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Abstract— The main idea of this paper is twofold: first of all to develop utilization processes for used tires and, second, to study and explain the serious ecological problems in the tire recycling and waste utilization sector in India. The paper presents improvements in a tire recycling process. The work for this paper involved making an in-depth analysis of the feasibility of the processes with an eye on financial and ecological performance, as well as on investment and profitability questions. A comparative analysis of different methods of tire recycling is conducted in order to enable the reader. Taking into account not only the end products but also keeping an eye on sustainable development. Furthermore, a full analysis of the pyrolysis process is presented, including the proportion of the products, as well as the technical and financial figures. The work de-scribes the main components and layout of the plant utilized for processing used tires and rubber products. Also, the working process itself is described.

Key words: Waste Tyre Recycling Processes, Environmental Sustainability

I. INTRODUCTION

Environmentally compliant recycling of used tires and rubber products is one of the biggest global ecological challenges today. For comparison, the level of recycling of used tires in Europe is 76% in the USA - 87%, Japan - 89%. Unfortunately in India, used tires are either just left by the roads (in case of puncture or damage) or buried. In India, typically, disposal of waste tires nowadays is simply carried out by “dumping” them to the nearest "convenient" location or by disposing of in a landfill. Used tires are, more of less legally mixed with other waste in landfills. The number of tires stored in the world in landfills is estimated at one billion pieces. Disposed of tires at landfills and dumps or scattered in the surrounding areas brings about a serious long time pollution impact. Lack of alternatives for tire recycling increases the number of tires stored in landfills. Certainly, this method cannot be called environmentally sustainable because tires degrade over a hundred years. Considering, that the amount of used tires constantly increased, it causes an irreparable damage to the surrounding nature.The technology to turn a potentially hazardous waste product (i.e., scrap tires) into a valuable resource is available now.

A. The Main Objectives

- The environmental sustainability.
- Maximizing the use of valuable raw materials.

This presentation contains a concise summary of the most common scrap tire recycling methods, as well as a discussion of prevalent uses for recycled tire rubber. The purpose of this work is to analyze and identify what is the best method of recycling rubber and improving environmental efficiency of the recycling of tires.

II. WASTE TYRE RECYCLING TECHNOLOGY

A. Retreading Technology

In the manufacture of a new tyre, approximately 75%-80% of the manufacturing cost is incurred in tyre body and remaining 20%25% in the TREAD, the portion of the tyre which meets the road surface. Hence, by applying a new TREAD over the body of the worn tyre, a fresh lease of life is given to the tyre, This process is termed as 'tyre retreading'.

B. Reclaimed Rubber Technology

Reclaimed rubber is one of technology to recovery waste tyre as raw material for tyre and rubber based product manufacturing.

C. Tyre Pyrolysis

Tyre pyrolysis produces fuel oil, gases, steel cords and carbon black from waste tyre, by combusting waste tyres(operating temperature above 250℃) in absence of oxygen.

D. Waste Tyre based Invention and Whole Tyre Application

There are wide range to recycle waste tyre as invention and whole tyre application. Many products made from waste tyres such as waste bins, flower plots, furniture and boat bumpers are common examples of waste tyre based invention.

E. Use of waste tyre as co-incineration in cement kilns

As the waste tyre have higher Gross Calorific Value (32-34 MJ/kg) than coal and other fuel, the waste tyre can be used as fuel substitution in many type of energy intensive industries such as metal manufacturing, glass manufacturing.

Using waste tyres in cement kilns is the one of the effective ways to deal with waste tyre by recovering energy locked in those tyres

III. THEORETICAL ANALYSIS OF WASTE TYRE RECYCLING TECHNOLOGY

The available technologies for waste tyre recycling in India are retreading, reclaiming, pyrolysis, co-incineration and other recycling techniques. This section describes each technology with its strengths, weaknesse.

A. Analysis for Retreading Technology

1) Strength:

One tyre can be retreaded more than 3-4 times. After each time of retreading, a tyre can recover and it’s life-span

equals 60%-90% of a new tyre. The price of tyre retreading is lower than buying new tyre by more than 45% Reduce the production cost and resources. The production process, production time, energy, capital cost and resources of tyre retreading are lower than new tyre. This technology suitable for the main manufacturers that is located near the source of waste tyre generation

2) Weakness:

Only bus and truck tyres can be retreaded. The passenger car tyre, light truck tyre and small tyre cannot retread because the structure of these tyres are not designed for retreading. Not all bus and truck tyres are retreadable. The used tyre has to go through a thorough quality check. The rejected tyre and used tyre after retreading for more than 3-4 times finally become waste, which need proper treatment and disposal.

3) Opportunity:

The price of retreaded tyre is lower than new tyre but the quality is quite same as the new tyre. This is good alternative for tyre user to select the low price yet good quality tyre.

4) Threat:

Convincing the consumers that quality of retreaded tyre is as good as new tyre is tough, as they have biased belief that the quality of a retreaded tyre is lower than a new tyre.

B. Analysis for Reclaimed Rubber Manufacturing

1) Strength:

The price of reclaimed rubber product is lower than natural rubber and synthetic rubber. The reclaimed manufacturing is testing their products in order to ensure the production quality. This technology does not require water in the production process. Thus, the waste water is not produced and the other pollution produced from the production process is comparatively less. All type of waste tyre can be used in production process but bus and truck tyres are preferred more. The reclaimed rubber product can use to make various rubber based products such as fenders, flooring tiles, rubber sheets for various applications, speed bumpers, hoses etc.

2) Weakness:

This business needs high investment cost for the machines and reactors. The owner and staffs need higher level of knowledge and experience. The limitation in using the reclaimed rubber is its lower quality as compared to new synthetic rubber hence cannot use 100% of reclaimed rubber.

3) Opportunities:

The reclaimed product can support material substitution for rubber based products. Consumers can save cost by using reclaimed rubber combined with original rubber. Financial supports as in subsidies and tax reduction/ waiving from government is required to help this kind of recycling initiatives.

4) Threat:

This technology is not popular in India only some manufacturing is used. The investment cost is too high. The technologies for reclaimed rubber process have to be transferred from other country

C. Analysis for Pyrolysis Technology

1) Strength:

The production process is simple. The pyrolysis plant required only pyrolysis reactors, cooling system, gas burning system, oil separation system, and wastewater plants. The quality of fuel oil from tyre is quite same as fuel oil from fossil fuel and has lower sulphur. All products from pyrolysis process can be sold and utilized. The price of products quite low. The pyrolysis reactors can be bought with in India and from China in cheaper deal.

2) Weakness:

The lack of labourers to work in the production process. Indian people do not want to work because it is considered dirty work. The cheap and poor quality of pyrolysis reactors can cause high cost of maintenance and there could be risk of leakage from the reactor. Pyrolysis plants need the support from the Government sector to register and allow the migrants to work.

3) Opportunities:

Pyrolysis plants owners and workers need to have information and knowledge about the technology to improve the production process and reduce environmental pollution. It can be a good alternative fuel oil instead of the fuel oil from petroleum.

4) Threats:

There are many pyrolysis plants and other companies who want to buy waste tyre as a raw material. This will increase the competition and hence the price of waste tyres in the future. Therefore it will be difficult to get enough waste tyres as main raw material. Air pollution and odour pollution are the major problems that cause complaints from people who live nearby these plant Local communities can hence protest to close the plant

D. Analysis for Invention and Whole Tyre Application Technology

1) Strength:

Waste tyre can be used to make various type of invention products without investing in expensive technologies for reprocessing the tyre. The products are abiding as a result of the characteristic of tyre. The investment cost is too low when compared to other recycle technology.

2) Weakness:

The products are not attractive and modern. The color and design of the products is not attractive to the consumers. This business is a handmade business that takes a long time for production. If the consumer orders too much products, the factory cannot produce it in time.

3) Opportunities:

The municipality and other local government should help the inventor to promote the products and provide markets for these creative products.

4) Threats:

Price of waste tyre is increasing than in the past.

There are many other recyclers who compete for waste tyre as a raw material such as pyrolysis factory, cement factory, reclaimed rubber manufacturing, and crumb rubber manufacturing. The consumers prefer to use other cheaper yet attractive and colorful products such as the plastic waste bins as compared to products made from waste tyre.

E. Analysis for Co-Incineration in Cement Kiln

1) Strength:

As the industrial incineration use high temperature in production process which suitable to burn waste tyre. Low investment cost of air emission control device because the

cemet kilns are already equipped with pollution control measures. Waste tyre can be completely destroyed in cement kilns. Acid gas emission can be trapped by CaCao3 in the raw mill.

2) Weakness:

The metal cords present in waste tyres can affect the tyre burning process. Cement industries are located far away from waste tyre generation source. As a result, the transportation is too high.

3) Opportunities:

The government should provide financial, technology support to cement industries to encourage the use of waste tyre as fuel substitution. Cement kilns if do not want to invest in reactors, they can purchase alternative fuel products generated in tyre pyrolysis plants. Such arrangement is beneficial to both kinds of industries.

4) Threats:

There is high competition among the waste tyre recycling manufacturing to buy waste tyre in their production process. Thus price of waste tyre is on the increasing trend. According to high consumption of waste tyre in other recycling plants, cement industries may lack access to waste tyre as feed material.

IV. RECOMMENDATION FOR MOST SUITABLE TYRE RECYCLING PROCESS

- Non-renewable natural resources make us look for ways to better use of valuable raw materials, than just burning it.
- The pyrolysis process is economically very beneficial and environmentally friendly.

Therefore, comparing the features of different methods, I am recommend the use of pyrolysis as the most efficient methods of recycling waste tyre.

V. PYROLYSIS OF WASTE TYRE

Pyrolysis is established technology that cooks material in the absence of oxygen, causing it break down. Emissions from the process are therefore controlled and completely environmentally friendly.

The pyrolysis method for recycling of used tyres is an innovative technique that uses a special mechanism to heat the used tyres in a closed vessel to melt down the tyre into the materials that they were made of.The pyrolysis reaction will produce carbon black, steel wire, gas, and furnace oil as by products of the recycling process.

Basically there are two types of technology being used in the country for generation of Tyre Pyrolysis Oil (TPO) viz. Batch Process and Continuous Process.

A. Advantages of Technology

- 100% wastage tyre recycling is achieved (zero waste).
- No chemical ingredients are used in process (environment friendly).
- During and after the process, no soil, water or air pollution is observed.
- Created economically valuable product out of wastage tyres.(These are industrial product that have a good market value and demand)
- The most cost effective wastage tyre recycling technology in the world.
- Raw material (wastage tyre) is cheap and easy to provide, these are the byproducts of tyre production.
- Each recycled ton of tyres preserves 10 tons of CO2 that is major greenhouse gas.
- It is a 100% pollution free process, thus making eco-friendly environment.
- The process can be applied to all rubber based materials.
- The system creates an alternate source of energy to replace petroleum products and natural gas.
- System gives the opportunity to governments and local administrations to deal with the wastage tyre problem to a great extent.
- The process of pyrolysis has duration of 4 to 12 hours, depending on the quantity and size of tyre (car tyre, truck tyre etc). During the process different vacuum values are applied in pre-determined temperatures and in different phases. Different gases are obtained and the condensed gas is stored as a fuel oil in tanks.

B. Scope of the Output Products

1) Pyrolysis Oil (Industrial Fuel Oil)

The pyrolysis oil is equivalent to Furnace Oil which is used as industrial fuel in many industries. Furnace Oil rates are around varies from 40 to 50 Rs/litre. Pyrolysis Oil rates are always less than Furnace Oil and are around approx 30 to 40 Rs/litre.

2) Carbon Black-

This carbon black is of lower quality as it has around 10% of ash content in it, as a result it is used in manufacturing lower grade quality products.

Carbon Rate- approx 1 to 2 Rs/kg.

Applications of carbon black-

- Used in steel industries for burning process.
- Used in footwear industries to make rubber souls.
- Used in polish industries.
- Used in ink industries.
- Used in color industries as pigment.
- Used by traders to mix with higher grade carbon.
- Used in Iron industries.

3) Steel Wires

These steel wires are easily sold to the steel scrap dealers.

Steel Wire Rate- approx 12 to 15 Rs/kg.

4) Gas

Gas produced by pyrolysis is a mixture of hydro carbon gases. They have sufficient calorific value that they can be sed in pyrolysis reactor's hating system as a fuel.

5) Heavy Oil-

This oil is of less quantity at around approx 50 to 100 litres. Heavy oil Rate approx 9 to 24 Rs/litre. Rates depends on where you are selling.

- Road Construction Industries rate would be approx. 10 Rs/kg.
- Auto Garage rate would be approx. 9 to 12 Rs/litre.

You can also use this oil as a paste on wood so that wood can catch the fire fast. And as a result consumption of wood is also decreased.

VI. COMMERCIAL PYROLYSIS PLANT SETUP

Fig. 1: Commercial Pyrolysis Plant

A. Features of the Pyrolysis Plant

- Hazardous waste is utilized to convert into useful Energy.
- Pollution free plant
- Chemical ingredients free process.
- Economically valuable product output.
- Plant effectiveness in all rubber based material.
- Easy availability of raw material (waste tyre/rubber)
- Eco friendly plant gives benefit to environment and other way government to reduce hazardous waste.
- Plant is totally maintenance free.

S. NO.	**Item**	**Contraction**	**Description**
1	Main (10 ton) Reactor	14MM BQ plate Capsule	6.6Meter*2.6Meter 14 MM Plate Thickness
2	Vertical Condenser OR Pipe condenser	5 MM MS Plate OR 4” MS Pipe 20 Nos C Class Pipe	600*2000 MM 4 Nos OR 4” Pipe 20 Nos with Header 16”*1500 MM
3	Insulation tank	5 MM MS Plate	800 MM*1500 MM cera wool insulation with aluminium sheet
4	Water seal tank	5 MM MS Plate	1000 MM*1800 MM
5	Gas tank	5 MM MS Plate	800 MM*1550 MM
6	Oil tank	5 MM MS Plate	800*2250 2 Nos 800 Liter*2 Nos
7	Water coolant pipe	8” OD Pipe covered with 12” Water coolant pipe	10 FEET length
8	Dust pipe	12”Pipe-3 Nos pipe	(1), 10 feet pipe (2), dust washer pipe (3), scrubber to blower pipe
9	Scrubber tank	5 MM MS Plate	800 MM*2750 MM with coolant pipe
10	Dust Blower	5MM MS Plate	5HP Blower with Motor
11	Hoist	2 HP HP 4” reduction gear hoist	1 Tons wire Hoist with Motor
12	Chain block	2 Tons chain block	2 Tons chain block with 10 feet chain for reactor door
13	Penal board	Reactor Penal board with 10 HP VFD Drive	Total motor controller temp. Indicator penal board
14	Submersible water pump	3HP submersible pump	Atlas brand 3 HP sb. pump for cold water supply
15	Gear pump	3 HP Gear pump	Atlas brand 3 HP gear pump for oil transfer

16	Mud pump	3 HP Mud pump	Atlas brand 3HP Mud for scrubber
17	Chimney	12" pipe chimney	20 feet for chimney pipe
18	Gas blower	2 Nos Gas blower 0.5 HP	2 Nos reactor gas blower
19	Extra gas burner	1 Nos gas burner	Extra gas burner
20	Cooling tower	Capacity 50 tons	3 HP 2880 RPM Motor
21	Hardware	As per reactor	Hardware for reactor pipe and pipe fitting
22	Reactor cover	Reactor cover insulation	With cerawool 1260 Temp 25 MM Two layer
23	Foundation	As per drawing	
24	Reactor gear box	Shricon brand	180 center 10 HP helical gear
25	Fire Brick & castable cement	500 Nos fire brick and castable cement-4+4 bags	For fire system

Table.1. Technical detail of 10 Metric ton Pyrolysis Plant

Equipment	Specification (10 MT)
Material	Waste tyres, Scrap rubbers, Plastic
Structure	Horizontal Rotation
Capacity for one batch	About 10 tons
Oil yield	40% - 45%
Carbon Black	30% - 35%
Steel Wire	11% - 15%
Gas	10% - 13%
Work Pressure	Atmospheric pressure
Main engine rotation speed	0.4 RPM
Fuels choice	Coal, Wood, Gas, Oil
Power	About 25HP
Cooling method	Water cooling
Cooling water consumption	Cyclic
Type of drive	External annular gear drive
Heating method	Direct
Type of installation	With foundation
Operating mode	Intermittent operation
Reactor dimension (MM) (Diameter*Length)	2600*6600 or 2800*6000
Reactor weight	About 12000kg
Total weight	About 34 MT approx

Table.2. Technical Specification of the Plant (10 MT capacity)

B. Technical Process Route of Pyrolysis Plant

- The waste tyre stream is subjected to temperature in the range of 250°C to 450°C under anaerobic (i.e. oxygen free) condition.
- This process causes rubber to break down and the organic component of the oil is converted in to a mixture of organic chemicals and incompressible gases.
- The vaporized gases will then pass through the heat exchanger and the oil gets condensed in liquid form. Water is being used as cooling media. This water is recirculated again for cooling.
- The non-compressible gas is fed to the heating system as a fuel thus entire reactor is 'Energy self-sufficient'.
- Then the steel wire and carbon black are removed.
- Entire process is batch process.

C. Precautions

- Open the door of reactor below 50°C
- Rotate the reactor at low rpm (around 0.4 RPM) .
- Observe pressure, temperature and leakages every time.
- Operator should be skillful.

VII. THE INFLUENCE OF PROCESS OPERATING CONDITION AND EXPERIMENTAL DETAIL

The composition of the pyrolysis products is influenced by the process operating conditions such as, feed size, operating temperature and pressure, residence time, heating rate and as well as the presence of catalytic medium.

Temperature: The increase in gas yield with a corresponding reduction in liquid yield with increase in temperature is due to vapour decomposing into permanent gases, and secondary re- polymerization as well as carbonization reactions of oil hydrocarbons into char. It is also a result of char loss and thermal cracking. Thus, gas yields dominate at higher temperatures.

A. Tyre Pyrolysis Product Yields under Different Operating Condition

1) For Radial Tyre (8000kg/Batch):

Experimental Condition		Yields (kg., %)			
Temp (°C)	Pressure (bar)	Oil	Carbon black	Steel	Gas
305	≤ 4.5	2720, 34.00	3425, 42.81	880, 11.00	975, 12.19
320	≤ 4.5	2820, 35.25	3180, 39.75	885, 11.06	1115, 13.94
345	≤ 4.5	3130, 39.13	2745, 34.31	885, 11.06	1240, 15.50
363	≤ 4.5	2950, 36.88	2640, 33.00	875, 10.94	1535, 19.18
375	≤ 4.5	2660, 33.25	2445, 30.56	880, 11.00	2015, 25.19

Table 3: End product percentage of radial tyre

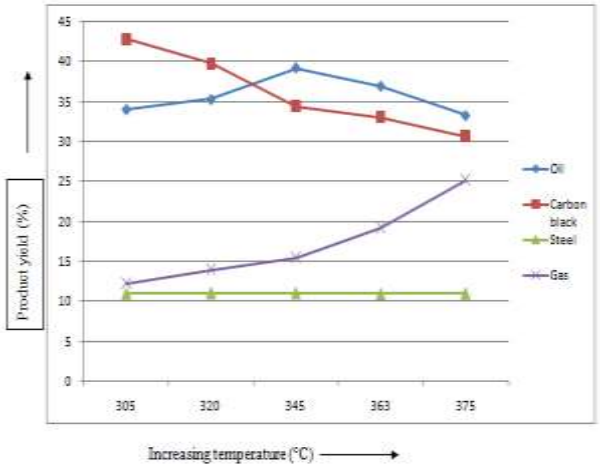

Fig. 2: End products of radial tyre

Product	Oil	Carbon Black	Steel
Rate (₹/Kg)	35	2	15

Temperature (ºC)	Products Value (in ₹)
305	1,15,250
320	1,18,335
345	1,28,315
363	1,21,655
375	1,11,190

Table 4: Economical Assessment For Radial Tyre

2) For Nylon Tyre (8000kg/batch)

Experimental Condition		Yields (kg., %)		
Temp (°C)	Pressure (bar)	Oil	Carbon Blak	Gas
295	≤ 4.5	3215, 40.19	3670, 45.88	1115, 13.94
310	≤ 4.5	3420, 42.75	3260, 40.75	1320, 16.50
330	≤ 4.5	3640, 45.50	2960, 37.00	1400, 17.50
355	≤ 4.5	3520, 44.00	2875, 35.94	1605, 20.06
370	≤ 4.5	3280, 41.00	2585, 32.31	2135, 26.69

Table 5: End product percentage of Nylon tyre

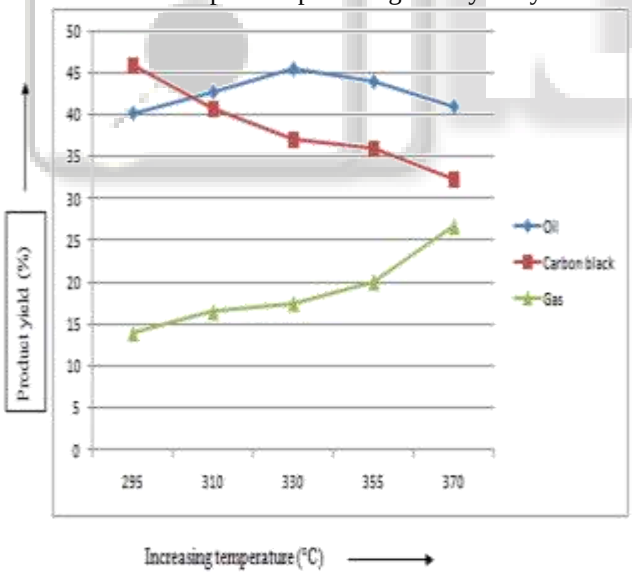

Fig. 3: End products of Nylon tyre

Product	OIL	Carbon Black
Rate (₹/kg)	35	2
Temperature (ºC)	Products Value (in ₹)	
295	1,19,865	
310	1,26,220	
330	1,33,320	
355	1,28,950	
370	1 19,970	

Table 5: Economical Assessment for Nylon Tyre

VIII. Conclusion

- On observing various process under different temperature we can say that tyre pyrolysis quantity range varies for radial tyres and nylon tyres
- Best product yield is obtained for radial tyre between temperature range 320ºC to 363ºC.
- For nylon tyre temperature range is feasible from 310ºC to 355ºC.

IX. Future Recommendation

- I would like to make suggestions to improve the efficiency of the plant. The suggestion include that the most effective way is to work on two or more of pyrolysis furnaces at one time, because excess gas from the first furnace can be used to heat the second. In each period of time furnaces are in different stages of the process. Phase shift between the two furnaces process chosen so that the second wave is going through a maximum gas production at a time when the first wave is in greatest need of fuel.
- Waste tyre management is becoming a challenge in India because of a large amount of tyre production and wide use of vehicles, but small amounts of recycling. Material flow analysis (MFA) is a systematic assessment of the flows and stocks of materials within a system defined in space and time. It connects the sources, the pathways, and the intermediate and final sinks of a material. We can use Material Flow Analysis (MFA) as a tool to identify and quantify the flows of tyre and waste tyre in India.
- Waste tyre recycling based power generation plant can established by using the hot water and gas.

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