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An Investigation of Pyrolysis, A Substitute Technology for Managing Agricultural Solid Waste in Indian Cities

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Abstract

To evaluate pyrolysis's potential as a substitute technology for handling municipal solid waste in India, this study explores the pyrolysis process. The thermochemical breakdown of organic materials at high temperatures without the presence of oxygen is known as pyrolysis. Both the physical and chemical phases of organic matter change concurrently, resulting in the formation of a liquid, a solid residue rich in carbon, and a gas that can be utilized as fuel. One of the processes in burning solid fuels, volcanic eruptions, and wood burning where lava comes into collision with greenery is pyrolysis. In the chemical industry, pyrolysis is commonly used to produce PVC, methanol, charcoal, activated carbon, and petrol. The procedure has also been used to transform solid waste into materials that can be disposed of securely. Pyrolysis has been frequently used in India to produce charcoal locally. Because of the extensive release of greenhouse gases into the atmosphere and the deforestation that occurs, this still presents significant environmental challenges. In the meantime, India still has significant problems with municipal solid waste control brought on by population pressure and urbanization. Indian States where tetra pak is now employed as a fuel source, lowering its prevalence in Municipal Solid Waste by over 80%, have effectively implemented pyrolysis energy recovery from MSW. Rubber and plastic waste, which are major environmental issues in India, can also be converted into useful energy by pyrolysis.

Keywords: *Thermochemical, Pyrolysis, Decomposition, Energy recovery, Municipal solid waste.*

1. Introduction

One of the technologies for recovering resources from recyclable matter that is developing the fastest is pyrolysis. Carbonaceous organic matter is thermochemical broken down during the process in the lack of oxygen, or very little of it. The organic matter changes in both its chemical and physical composition at the same time, becoming a gas, a liquid, and a residue that is rich in carbon. Carbon dioxide (CO2), synthetic gas, methane (CH4), hydrogen (H2), and carbon monoxide (CO) gases make up the gaseous product, while pyrolysis oil (a biofuel) and ash/char make up the solid and liquid products, accordingly. All of the byproducts of pyrolysis are fuels. In specialized heat/power facilities, syngas and pyrolysis oil can be used to directly generate heat and electricity. Furthermore, syngas has been employed in petrochemical and refinery operations as a fundamental chemical.

The main objective of pyrolysis in the context of managing municipal solid waste (MSW) is to transform MSW into components that are both chemically and biologically viable and need the least amount of storage space. [1] As part of integrated MSW management, the secondary objective of pyrolysis is resource/energy recovery from solid waste. In place of the traditional solid waste management (SWM) techniques, such as dumping, burning, open-air burning, composting, and anaerobic and aerobic digestion, pyrolysis is being considered in this study. Due to their comparatively high cost, inefficiency, and greenhouse gas emissions that endanger the environment over time, some of these approaches are not sustainable.

2. The Fundamental Pyrolysis Process

Pyrolysis is essentially a thermal-chemical process that, typically in the absence of oxygen, breaks down carbon-rich materials into bio-oil, syngas, and char. Due to their high level of refinement, the products can be utilized either directly as extremely effective fuels or indirectly as basic components for various chemical and material industrial processes. [2] Pyrolysis is a suitable processing method for materials including food scraps, coal, animal waste, human waste, cardboard, rubber, biomass, and paper. All things considered, lignin and carbs (cellulose and hemicellulose) make up the majority of biomass. [3] While the lignin burns into a residue rich in carbon, the carbohydrate components break down into volatile, lower molecular weight products. This process entails a sequence of intricate chemical reactions and physical transformations that are sparked by high temperatures.

Understanding the fundamental mechanism of pyrolysis is crucial for designing practical application techniques. The biomass experiences simultaneous changes in its chemical and physical states during the pyrolysis process. [4] The feedstock changes in size, color, weight, and mechanical strength. The feedstock can disintegrate up to 80% of its weight at 3500C, at which point the leftover feedstock chars. (figure 1) The amount of char generated would further decrease to hardly 9% by weight of the original feedstock if heating was extended to roughly 6000C.

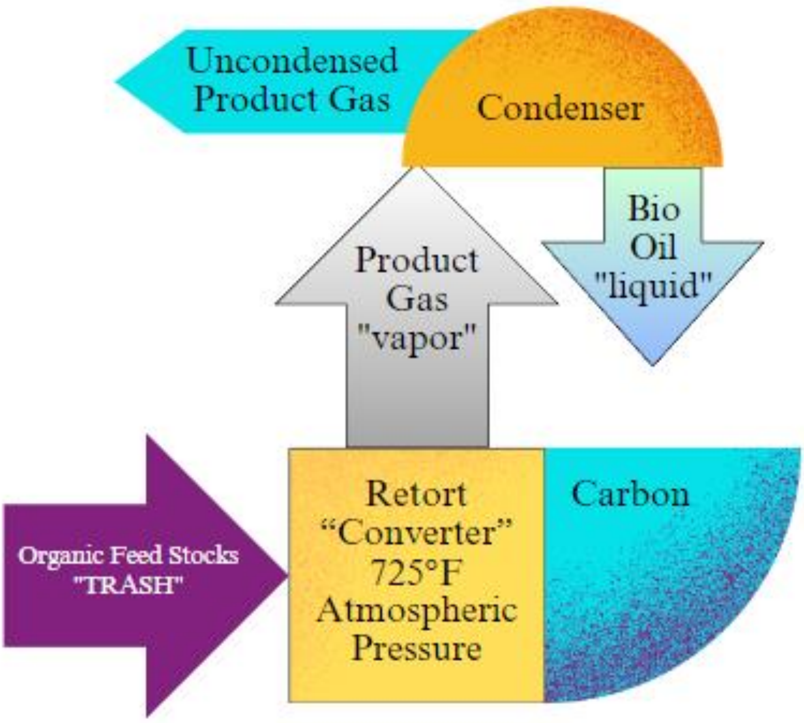

Figure 1: fundamental pyrolysis process

[5] Pyrolysis starts with the feedstock's dehydration in chronological order. This process, known as slow pyrolysis, takes place at temperatures lower than 3000C and is what causes weight loss as well as the creation of CO2, CO, char, and water. Following the dehydration process, the biomass is fragmented (flash and quick pyrolysis) at temperatures higher than 3000C. Here, the biomass breaks down into light flammable volatile molecules and a few anhydrous glucose compounds. [6] Divides the pyrolysis products into three categories: (Table 1) chars, tars with a higher molecular weight, and volatile compounds with a molecular weight below 105.

Table 1: pyrolysis oil chemical composition

Constituent Compound	Composition
Anhydrosugars	**20-35%**
Water-insoluble pyrolytic lignin	**6-15%**
Other oxygenated compounds	**9-25%**
Organic acids	**15-35%**
Non-polar hydrocarbons	**3-17%**
Water	**35-40%**

Apart from pressure, dwell time, and humidity, other factors that affect biomass pyrolysis include heating rate, composition of feedstock/substrate, ambient environment, and catalyst presence. Figure 2 illustrates the three common types of pyrolysis reactors that are used in practice: rotary kilns, rotary hearth heaters, and fluidized bed reactors.

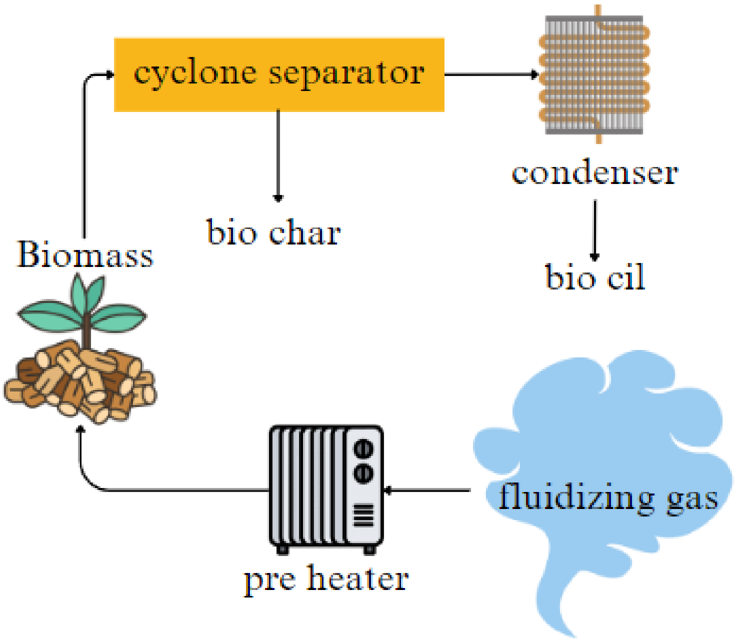

Figure 2 pyrolysis reactors

3. Municipal Solid Waste Pyrolysis

The creation of solid waste is an inescapable byproduct of human activity, and how it is managed directly affects both public welfare and health. [7] The amount of solid waste produced worldwide has increased dramatically over time, as has the complexity of its composition. The increased usage of electronic and plastic consumer goods on top of this presents a significant problem for the organizations in charge of managing MSW. [8] The UN Development Programme links global improvements in living standards, urbanization, and economic development to the growing complexity and volume of MSW.

The scenario is the same in India. It is estimated that municipal authorities in developing nations, including India, spend a minimum of thirty percent of their yearly budget on managing fifty to seventy percent of the MSW accumulated within their jurisdiction. In India, open damping is still the most often used technique for getting rid of solid waste. [9] Because of the significant environmental and health risks this presents to the local population, the Local Government Minister was forced to order the famous Dandora Dumping Site to be relocated to Ruai in 2003. Open dumping, combustion, burning in the open, and landfilling are examples of conventional MSW management techniques. However, because of rising expenses, a lack of available space for expansion, and possible environmental problems, some of these approaches have proven to be unsustainable. [10] This caused the focus to move to the pursuit of more environmentally friendly MSW management techniques, with an increase in interest in MSW digestion, thermal treatment, and composting as well as a focus on energy recovery and resource integration and integrated solid waste management.

Pyrolysis's Useful Applications in MSW Management

This article describes several pyrolysis facilities that have been created globally that combine pyrolysis with recycling and composting. The plants can process 200,000 tonnes of material annually, of which 126,000 tonnes are reserved for energy and material recovery while the other 96,000 tonnes are either composted or recycled. Furthermore, 18.3 MW of electricity is produced. [11] To "reduce climate change, meet the standards for sustainable waste management, and offer a solution for the treatment of hard and industrial waste," the UK-based company has created these additional units with great expectations. The following section discusses some other intriguing advancements in the use of pyrolysis for MSW management.

Utilizing Pyrolysis to Extract Solid Waste in Space

This created a pyrolysis plant prototype for recovering mixed solid waste from spacecraft. With a double-stage reactor that can treat one kilogram of solid waste every cycle, this unit is comparatively straightforward. [12] The main byproducts from the first stage gasify the majority of the carbon produced by the catalytic cracking of tars at 1000–11000C in the second chamber. Additional gases are also produced during this process. To operate the system, an artificial neural network would be created. This is a promising technology that can be used to manage solid waste in spacecraft applications while using the byproducts for other processes without negatively impacting the environment. [13] Furthermore, because of the extremely high temperatures involved, the system would need to be controlled at a high rate, which is what they wanted to achieve by creating an ANN. It would also be fascinating to find out if other car models could use this kind of technology.

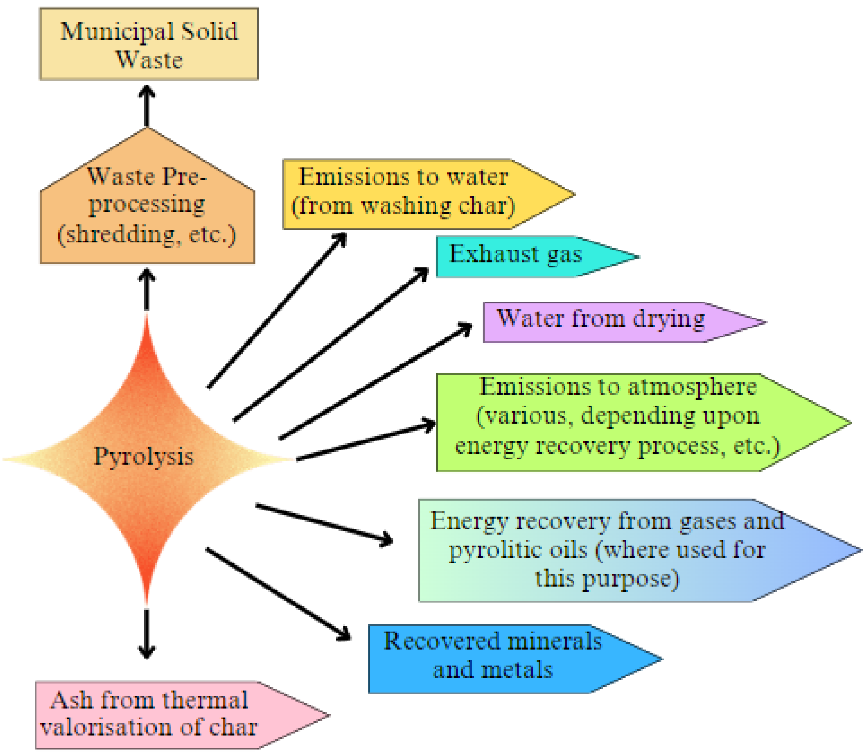

Figure 3: An overview of MSW pyrolysis

Waste Tetra Pak Packages: Pyrolysis

All around the world, aseptic packaging materials like Tetra Pak are used to package milk, drinks, soy, juices, and nectar. The global adoption of tetra pak packaging has been justified by its capacity to extend the shelf life of perishable goods by a minimum of six months. It was predicted that by 2007, there would be at least 137 billion Tetra Pak packets in use worldwide each year. [14] In Kenya, yogurt, drinks, and processed milk (sometimes known as long-life milk) are frequently packaged in tetra packs. Consequently, trash tetra pak packaging often accounts for a sizeable amount of MSW worldwide as well as in India. Finding a sustainable method for the easy disposal of waste materials, including tetra pak containers, is crucial to salvage any useful components from the garbage.

Three raw elements make up the tetra pak packaging material: 20% light polyethylene, 5% aluminum, and 75% duplex paper. The fibers can be utilized to make paper towels, tissue paper, and fine writing paper in the paper industry, while the aluminum and polyethylene components can be recovered through pyrolysis, reprocessing, and burning. Different pyrolysis modes and temperatures (400-6000C) were selected for the batch reactor. After that, the byproducts of pyrolysis were gathered and measured. These consist of pure aluminum, gas, wax, and carbon residue. [15] According to the study, the char produced by the procedure may be utilized as fuel because it had a low ash level and a high calorific value. It was discovered that carbon oxides predominated in the gaseous product. Additionally, two processes were identified by thermo-gravimetric measurement of the pyrolysis process: primary cardboard deterioration below 4000C and polyethylene dissolution above 4000C.

The findings show that used Tetra Pak packaging may be properly recycled using pyrolysis to produce valuable items. This is a good study, and the specifics of its conclusions offer a methodical way to remove tetra pak and similar waste products from the MSW stream and turn them into beneficial goods. To evaluate the three pyrolysis products developed in this study's viability for real-world applications, it is crucial to determine their respective calorific values.

Polymeric Material Pyrolysis (Rubber & Plastics)

The globe has seen a massive rise in the use of polymeric materials over time, especially rubber and plastics. Approximately 2.3 billion tonnes of plastic were produced worldwide in 2009 alone, with 54% of that quantity ending up in landfills. The majority of rubber also ends up in solid waste disposal facilities, mostly used tires. Plastic bags are the primary packing method used by Indian shoppers, and the country is seeing an increase in the use of tires and plastics. In addition, a growing number of Kenyans are acquiring cars, and the country's use of motorbikes—also referred to as bodaboda taxis—is contributing to the country's rapidly rising car count. Tyre usage is undoubtedly increasing as a result of this, which implies that tires' share of the resulting MSW is rising. All things considered, waste polymeric materials provide a significant disposal challenge that has sparked a lot of attention. Furthermore, rather than combustion and landfilling, their management is concentrated on sustainable reuse, recycling, and recovery.

An additional choice for recovering useful raw materials from waste rubber and plastic is pyrolysis. In addition to traditional heating, microwave heating has also advanced recently to control the pyrolysis of waste polymeric substances. Tires differ in terms of brand, purpose, and size composition. Car tyres' chemical composition is roughly 14% polyisoprene and 27% synthetic polymer. Among other things, the bio-oil generated in this instance contains xylenes, benzene, limonene, and toluene and has a very high calorific value. Energy-producing bio-oil is frequently utilized as a feedstock in refineries or as a storehouse for aromatics and limonene. The non-volatile elements and carbon make up the solid product. The carbon-rich solid is utilized as a smokeless fuel, in the synthesis of activated carbon, and the tire industry.

Similar to tires, pyrolysis of plastics has attracted a lot of attention lately. Numerous polymers, such as polypropylene, polyethylene, polyethylene terephthalate, polyvinyl chloride, and polystyrene, have been successfully evaluated for pyrolysis using both conventional and microwave heating methods. Because plastics don't absorb microwave energy well, another microwave-absorbent material needs to be used for microwave pyrolysis.

Nonetheless, the traditional process of pyrolyzing pure polymers has been extensively researched, primarily yielding gases and liquids. A small amount of solid results have been recorded in a few studies. All things considered, plastics and waste plastic may be successfully pyrolyzed (in a microwave or traditional oven) to produce essential hydrocarbons with a high calorific value and also valuable oils and fuels. Research indicates that microwave pyrolysis is the best method for turning waste plastic—whether simple or complex—into these useful goods.

Carbon from MSW Pyrolysis as a Soil Amplifier

Biochar is a by-product of biomass pyrolysis that resembles charcoal. The product's ability to store carbon for extended periods has been investigated to reduce greenhouse gas emissions. The majority of research done in the Amazon basin has revealed notable changes to the soil that have improved crop yields and long-term soil carbon sequestration. It recently demonstrated the striking effects of fire on American soils, particularly in the maintenance of grass and woodland plants. This is so because fire transforms plant biomass—typically in the form of charcoal—into stable carbon. The United States Centre for Sustaining Farming and Natural Resources researched to evaluate the potential of biochar—a soil supplement made from the pyrolysis of waste organic matter. In Washington, USA, an assessment of biochar derived from a variety of feedstocks was carried out to determine its impact on five different types of soil. Table 2 provides a summary of their findings.

Table 2: Composition of carbon and nitrogen in biochar derived from various feedstocks

Type of Feedstock	Content of Carbon	Content of Nitrogen
Activated Charcoal	97%	**0.67%**
Digester Fiber	77%	**Very high**
Herbaceous Feedstock	70%	**Very high**
Woody feedstock	**>85%**	**196-798 (C:N Ratio)**

Benefits and Drawbacks of Pyrolysis of MSW

Comparing MSW pyrolysis to other techniques for recovering resources from solid waste, there are a lot of benefits. First of all, the process is very adaptable, making it suitable for treating a variety of solid wastes due to its ability to quickly adjust to changes in the feedstock's content. Second, pyrolysis is a rather easy technology that may be applied even in spacecraft and other small-scale practical applications. Thirdly, the procedure can be carried out at pressures low enough to reduce the need for feedstock pretreatment. Furthermore, pyrolysis produces a variety of valuable compounds, and the system can be designed to minimize the amount of useless byproducts produced. It's also crucial to remember that MSW pyrolysis drastically lowers the amount of space needed for storage, with vital components being appropriately preserved as char. After that, these elements can be recovered through gasification or incineration. As a result, MSW pyrolysis can be utilized as a pretreatment technique for other waste management procedures in addition to being a major waste treatment alternative. Because pyrolysis uses a limited amount of oxygen, it does not produce a lot of air pollutants that contribute to environmental pollution.

Nevertheless, despite the enormous potential of pyrolysis as an MSW management alternative, there are a few things to keep in mind that can restrict its uses. First, there's a chance of producing residues that could be hazardous, like unreformed carbon, a few inorganic chemicals, and inert mineral ash. Second, certain potentially harmful air emissions might be released. These emissions include sulfur dioxide, acid gases, dioxins, oxides of nitrogen, and certain particles. One possible barrier to the applications of pyrolysis has been identified as the intricacy of its product stream. This is dependent on the pyrolysis process itself, though, which is controllable enough to change the manufactured goods stream.

MSW Pyrolysis's Economic Viability

There are currently at least 100 facilities operating worldwide and roughly 150 businesses selling MSW pyrolysis and gasification systems. Each year, these systems can process over four million tonnes of MSW. MSW pyrolysis has been used on a commercial basis in China, Japan, India, Europe, and the United States. Numerous scientific investigations have also demonstrated the commercial viability of MSW pyrolysis. Self-sufficient and self-regenerating pyrolysis facilities with a daily capacity of up to 100 tonnes have been created in the USA. There is a city garbage pyrolysis factory in Delhi, India, that can process 2000 tonnes of MSW each day. These goods have an economic yearly turnover of at least 27% and are used as fuels and to generate energy. Therefore, it is evident that MSW pyrolysis offers a viable solution to both the energy and economic crises the current world faces as well as the MSW management threat. A brief internet search reveals a variety of contemporary, reasonably priced pyrolysis machines that are suitable for treating plastics, tires, and MSW in general—even on a small scale.

4. Conclusion

To evaluate pyrolysis's potential as a substitute technology for MSW management in India, this study discusses the process. The thermochemical breakdown of organic materials at high temperatures and without oxygen is known as pyrolysis. The organic matter separates into a gas, a liquid, and a residue that is rich in carbon as a consequence of simultaneous changes in its chemical makeup and physical condition. However, resource recovery is a secondary objective of MSW pyrolysis given the enormous

MSW management difficulty that India and many other developing nations are facing. The main objective is to manage MSW by using pyrolysis to reduce storage volumes and transform them into more durable, recyclable, and useable goods. Despite the equipment installation's initially high cost, MSW pyrolysis remains a feasible alternative from an economic standpoint. In addition, given the current global energy, economic, and environmental issues, the technology will undoubtedly have long-term ecological advantages that exceed its initial costs.

Abbreviation

CO2 – Carbon dioxide

CH4 – Methane

H2 – Hydrogen

CO -Carbon Monoxide

SWM – Solid Waste Management

ANN – Artificial Neural Network

PMP – Polymeric Material Pyrolysis

Competing interests

The authors declare that they have no competing interests.

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Authors' contribution

Author A supports to find materials and results part in this manuscript. Author B helps to develop literature part.

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