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Full Length Research Paper

Design and Fabrication of a Plastic Pyrolysis-Densifier

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ABSTRACT: Plastic trash disposal is becoming more of a global issue as a result of industrialization and population growth. Waste disposal is one of Nigeria's most serious issues. Such garbage is made up of polymers and plastics, which have been found to be challenging to treat in studies. Inadequate waste management in Nigeria is exacerbated by the country's higher population density. Plastics are low-cost, lightweight, and long-lasting materials that may be easily molded into a variety of items for a variety of applications. One of the most essential measures currently accessible to decrease these impacts is recycling, which is also one of the most dynamic areas in the plastics business. A permanent solution is now available because to recent developments in pyrolysis research. The goal of this study was to design a plastic pyrolysis densifier for producing building materials such as pavers, floor tiles, solar roof tiles, and fence posts using plastic as a feedstock. By fabricating a pyrolysis machine, billions of kilograms of plastic might be saved from landfills and transformed into oil, resulting in an environmentally friendly and profitable solution to plastic waste. The plastic densifying machine is made up of five major components: a hopper, a screw driver, a barrel and nozzle (die), heaters, and a control system. The nozzle and barrel are the main components of the machine, via which the crushed particles are sucked into liquid. The barrel containing the screw (mixer) is the device's core component, with its length heated by the gas burner. A heating control mechanism regulates the heat used to melt the crushed plastics. The molten plastic is conveyed to the barrel opening by a motor-driven screw.

Keywords: Plastics recycling, plastic densifier, pyrolysis and plastics

INTRODUCTION

Nigeria generates over 32 million tons of solid trash every year, one of the biggest volumes in Africa. Plastic accounts for 2.5 million tons of that total (Duru, Ikpeama, and Ibekwe, 2019). The combination of low-cost, lightweight, chemical and corrosion resistance qualities has increased the usage of plastic materials for packing and storage over other materials (Duru et al., 2019; Kehinde, Ramonu, Babaremu, and Justin, 2020). As a result, their global share of home solid waste and environmental impact are increasing. To counteract these problems, both industrialized and developing countries have implemented and continue to improve their plastic waste disposal, collecting, and recycling systems. In Nigeria, which has a population of roughly 186 million people, there is little or no evidence on plastic items in city neighborhoods and their disposal techniques, collection, and recycling (Duru et al., 2019). There are a few plastic garbage collection firms in a smaller number of cities, and management operations for the larger proportion of plastic debris that is not processed for recycling pose current and potential environmental problems.

The proposed project aims to fabricate and test a machine to produce oil, building materials like pavers, floor tiles, solar roof tiles, and fence posts from waste plastics. The system will be low cost and environmentally friendly. As we know, hydrocarbons, including the elements of

carbon and hydrogen, are both plastics and petroleum-related fuels. A pyrolysis process is an option for waste-to-energy technology to supply biofuel to replace fossil fuels. The benefit of the process of pyrolysis is its capacity to handle unsorted and dirty plastic.

The pre-treatment of the material is accessible. Plastic is needed to be sorted and dried. Unlike incineration, pyrolysis is often a non-toxic or non-environmentally damaging emission. The plastic densifiers utilise plastic as a feedstock to generate building materials like pavers, solar roof tiles, and fence posts.

Plastic waste disposal is becoming a global issue as a result of industrialisation and population growth. One of Nigeria's most important challenges is waste disposal. Such waste is made mostly of polymers and plastics, which have been shown in studies to be difficult to treat. The country's rising population density is one key factor leading to Nigeria's inadequate waste management. As a result, the densifier is designed to process and recover non-rigid plastic from industrial waste, households, and washing lines.

Objective: This research was aimed at the following purposes;

- design and fabrication of a plastic densifying machine for effective waste management.
- The development and evaluation of the device to produce building materials such as pavers, solar roof tiles, and fence posts.

Plastic definition and recycling of plastics

Plastics are composed of polymers, which are long-chain molecules. Hydrocarbons generated from coal, natural gas, oil, and organic oils can be converted into polymers with desirable characteristics (Jassim et al., 2016). Plastics are one of the most commonly utilized materials in our daily lives. They are able to make our life easier. They are frequently employed in the packing and processing of things such as electronics, automobiles, and so on. Plastics are lightweight and easily formed. It is critical to reuse them while also protecting natural resources.

Plastics have indeed supplanted wood and metals (Qureshi et al., 2020). As a result, the consumption of plastic has risen. In 1862, Alexander Parkes invented plastic (Brydson, 1999). Polymerization shapes them and gives them a high molecular mass. Other chemicals, in addition to polymers, can be incorporated in plastics to lower costs and improve performance. Molding or extrusion can be used to shape these polymers into the required shape (Qureshi et al., 2020). Plastics are classified into two types: thermoplastics and thermosetting polymers (Jayswal, Kumar, Pradhananga, Rohit, and Bahadur, 2017; Zhang et al., 2020). Thermoplastics can be repeatedly softened and melted if enough heat is applied (Jayswal et al., 2017). They harden after cooling and can be used to make new plastics items (Jayswal et al., 2017). Thermosetting plastics can only be melted and produced once. Because repeated heat treatment of such plastics is undesirable, they stay stable after solidification (Duru et al., 2019; Jayswal et al., 2017).

Epoxy paste, formaldehyde phenol, and more examples (Jayswal et al., 2017). The Society of Plastics Industry (SPI) has classified plastics into the following categories based on their application and chemical composition: PET (Polyethylene Terephthalate), HDPE (High-Density Polyethylene), PVC (Polyvinyl Chloride), LDPE (Low-Density Polyethylene), PP (Polypropylene), PS (Polystyrene), and Others (Jayswal et al., 2017).

According to Kehinde et al. (2020), any plastic material whose property makes it possible to become soft and melt under heat and be moulded or reshaped when cooled by taking the form of a desired formed mould thermoplastic. The different types and applications of thermoplastics are represented in (Table 1). The most characteristic property of thermoplastics is that they can meet again when reheated. Styrene and acrylics are the most famous examples of thermoplastics that have been found in school labs and possibly the largest (Kehinde et al., 2020). Unlike thermoplastics, when reheated, thermosetting plastics will not be softened or molten, although they can mellow and melt under high temperatures in the first place (Duru et al., 2019; Kehinde et al., 2020).

When molten, they can be moulded into the shapes they were in before freezing, but they then become permanent in the conditions they were in, and any further heating would either render them brittle or cause them to catch fire (Jayswal et al., 2017; Kehinde et al., 2020). The most common examples of these polymers are polyester resins used mostly for glass-reinforced plastics work and those used principally in the fabrication of Formica for kitchen work surfaces, such as melamine formaldehyde (Kehinde et al., 2020).

Converting these plastic wastes into an energy commodity is a potential alternative to energy scarcity and environmental damage in Auchi and Nigeria in general. Plastic trash will be pyrolyzed in a hybrid pyrolyzing machine to produce bio-oils that can be utilized to make valuable chemicals or fuels.

Plastics are heated and evaporated in the pyrolysis reactor, and the resulting vapour is transported to the shell and tube condenser for condensation (Velghe et al., 2011; Zhang et al., 2020). Several reactor configurations were used to achieve waste pyrolysis. The variance in the heating system caused by the reactor architecture is critical in the delivery of pyrolysis materials.

Popular heating methods include heating reactor walls, gas or solid heat carriers, and a combination of the aforementioned processes (Zhang et al., 2020). A fluidized bed reactor with bed material heating is a common reactor design for pyrolyzing waste. This study intends to locally

Table 1: Types, properties, and applications of thermoplastics (Duru et al., 2019).

Type	Properties	Application
Polyethene (PE)	Translucent, rigid and semi-rigid, chemical resistance, waterproof and low cost	Packaging (plastic bottles, bags, wraps, and films), construction
Polypropylene (PP)	Translucent, rigid and semi-rigid, chemical resistance, fatigue resistance, heat resistance and living hinge property	Packaging and containers, toys, medicine, automotive parts, tubing, furniture, Laboratory equipment
Polyethene terephthalate (PET)	Wear resistance, low coefficient of friction	Bottles, textiles, electricals, cosmetic containers
Polyvinyl chloride (PVC)	Fire retardant, durability, chemical resistance	Pipes, insulation, footwear, automotive parts
Polystyrene (PS)	Lightweight, rigid	Insulation, packaging
Polymethyl methacrylate (PMMA)	High UV light and chemical resistance, transparency, durability	Automotive lamp covers an alternative to glass in specific applications

build a fluidized bed reactor to accommodate the current reality of plastic waste generation and management.

Recycling methods

Avoiding waste generation is the most effective and long-term waste problem solution. The 3R principle is promoted through an environmentally friendly lifestyle, consumption of goods, and waste disposal (Jassim et al., 2016). The first principle (Reduce) informs us that we can reduce waste volume by restricting unneeded product consumption (Jassim et al., 2016). The second (Reuse) explores the possibilities of reusing a product that is traditionally seen as disposable (Jassim et al., 2016).

The third principle (Recycle) states that not all waste can be avoided, just as not all products can be utilized repeatedly (Jassim et al., 2016). Waste processing systems that include secondary processes enable waste utilization based on the following methods:

Chemical recycling is the act of recycling waste items by partially modifying their chemical structure via chemical processes, such as producing fuel oil from plastics, heat-insulating materials, packaging, and so on (Jassim et al., 2016).

METHODOLOGY

Design of plastic pyrolysis-densifier

Pilot-scale plastic pyrolysis reactors are drums with circumferentially located blades that rotate to mix plastic and are heated externally. To facilitate the movement of the plastic, the drum is frequently tilted by a few degrees. Rotating kilns can operate at higher temperatures while also mixing the plastic continuously. Figure 1 shows the reactor's CAD drawing. There were plans to use 304 stainless steel sheets for the inner diameter and length of the rotary kiln pyrolyser. The gas burner is used to warm up the heat carrier during the experiment. It is controlled by two K-type thermocouples, one in the middle and one at the bottom of the reactor chamber, owned by the PID unit. The rotary kiln reactor powered by a transducer can be set to rotate at any speed between 0 and 20 rpm.

Fabrication process

Machine fabrication includes a variety of techniques such as lathe machining, drilling, boring; keyway cutting; slotting; oxyacetylene gas welding; grinding, and electric welds. The machine's schematic is shown in (Figures 1-3). Accessibility and ease of assembly were critical considerations throughout the creation of this model. Parts are carefully connected thoughtfully. The first step is to weld each flange to its corresponding location. Before the endplate is welded to the jacket, the hot side bushing is welded to the endplate. The bottom of the jacket is filled with water, and the weld is checked for leaks. Then, the jacket is butt-welded to the input and output pipes. The cold side sealing pipe can now be welded with the one angled bar. The cold side jacket endplate can then be welded to this. The cold side endplate can be bolted on after the auger has been inserted and the hot side bearing met.

Barrel/Reactor

The barrel diameter is 1386 mm, and the L/D ratio ranges from 10 to 30. For thermoplastics, the L/D percentage is higher, while for elastomers, it is lower. Materials are moved through a barrel by rotating a screw fed by gravity. The channel depth is maintained when the resin is poured into the barrel. The channel depth gradually decreases as the plastic material is melted. When the molten plastic and oil are mixed, they are pushed through the nozzle. The photographs in (Figures 4-5) show the specifics. The mixer is made from a 1400 mm long cylinder rod (50mm diameter). The shaft is made of steel and is used to rotate the knives and fix the support posts (Figure 3).

Heating source selection

The heating source must be selected after the reactor geometry has been determined. An LPG gas burner and

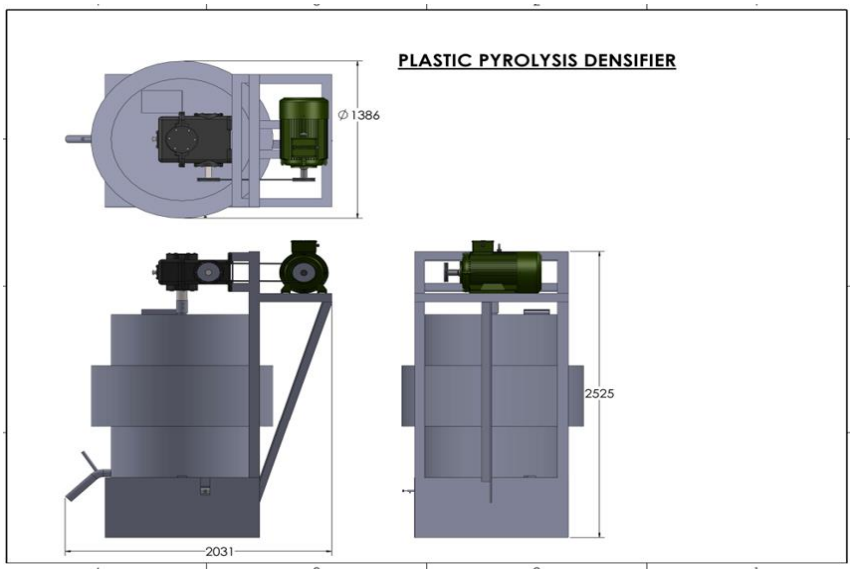

Figure 1: Plastic pyrolysis reactor cad drawings.

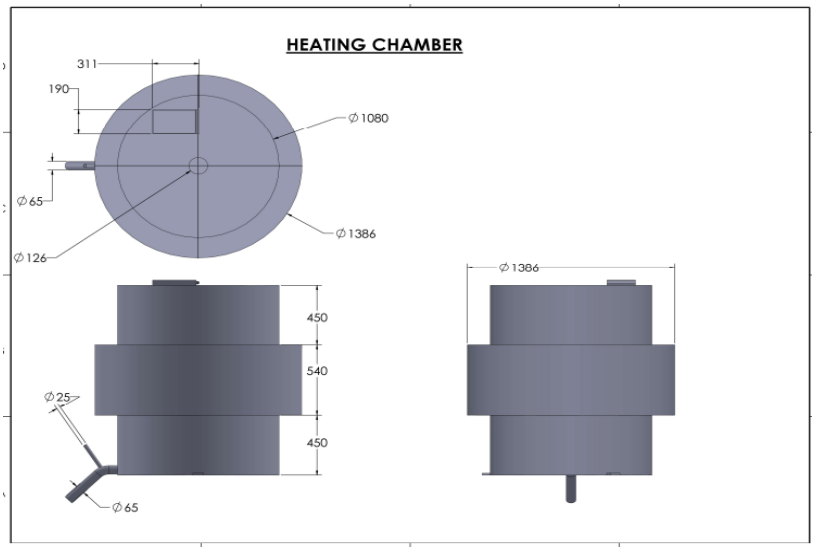

Figure 2: Heating chamber parts to be fabricated.

heating chamber were set. Figure 2 depicts the conceptual design for heating the reactor in the plastic pyrolysis plant. It is possible to gradually raise the reactor's temperature using this system, making it the most efficient for heat transfer. The heat was generated by subsequent mixing and mechanical work, which kept the melt stable (Figure 4).

Control/Instrumentation Box

The motor speed and barrel temperature are both controlled by the instrumentation box. The power supply is connected to the motor controller through a box switch. Afterwards, attach the motor to the motor controller. With an input voltage of 220V AC and a voltage regulation range of 50-220V, the maximum power is 2000W. Several critical parameters must be met for the system to function correctly.

Application and material used

The materials used include; mild steel, stainless steel, plastic, angle bars, k- type thermocouple, leather gasket,

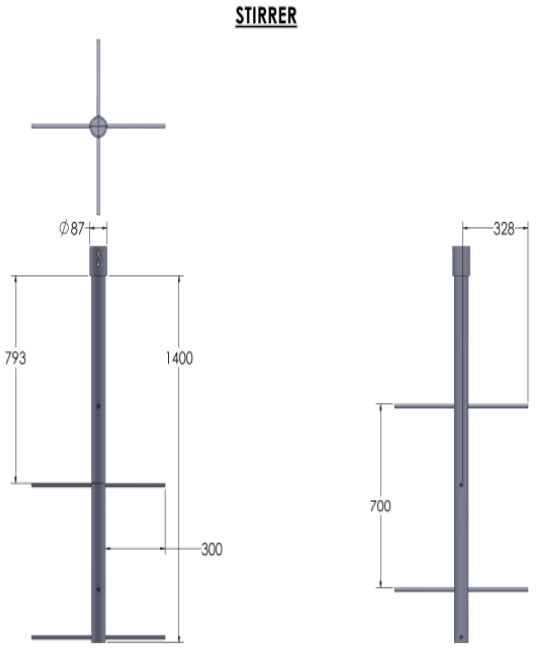

Figure 3: The CAD diagram of the mixer/stirrer.

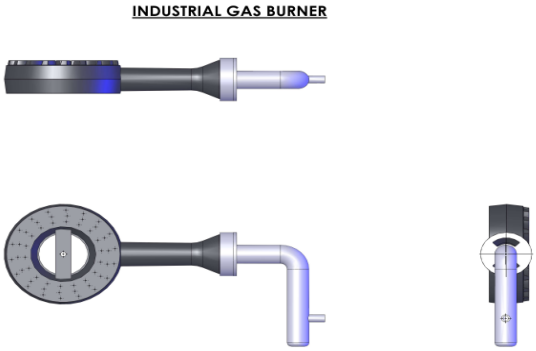

Figure 4: Industrial gas burner as heating source.

and transducer. The plastic wastes are collected from municipal solid waste locations within the Auchi Polytechnic Campus, Auchi Communities, in Edo, Nigeria. They usually consist of shampoo bottles, plastic bags, beverage bottles, and pure water sachets. The different types of plastic materials that can be used in the extrusion process are Polyethylene, Polypropylene (PP), Acetal, Acrylic, Nylon (Polyamides), Polystyrene, Polyvinyl Chloride (PVC), Acrylonitrile Butadiene Styrene (ABS) and Polycarbonate. The extrusion process is used for manufacturing rods, plates and tubes, wire and cable coating, hose liners, hose mandrels, filaments, sheets, multilayer film, medical packaging and food packaging, sheathing, and jackets (Figure 5).

Theoretical design of the plastic densifier

The plastic pyrolysis plant's general design was completed in three steps: preliminary heat calculations, a process flow diagram, and a piping and instrumentation schematic. Heat calculations were performed to document temperature, mass flow rate, and volumetric flow rate at various places throughout the facility.

Figure 5: Side view-photograph of the plastic pyrolysis machine.

Figure 6: Front view-photograph of the plastic pyrolysis machine.

The process flow diagram and the piping and instrumentation schematic were then created using these numbers (Figure 6).

Initial calculations

The plastic to be paralyzed is first placed in a hopper and then heated to a molten condition using waste vegetable oil before exiting the reactor. When the plastic enters the reactor at room temperature, it is predicted to attain a temperature of 536°F. The temperature of the paralyzed plastic will progressively climb in the reactor until it reaches 896°F. There will be some char and a lot of fuel produced. To accomplish the appropriate temperature fluctuations, the following head calculations were performed at the reactor. The initial measurements were based on heat, estimated gas molar masses, estimated densified plastic

molar masses, and volumetric flow rates. The difference in heat per mass of plastic entering the reactor was calculated using Equations (1) and (2) below:

$$\Delta q\ reactor = (\mathrm{C\ p}\ \Delta \mathrm{T} + \Delta \mathrm{h}^{\circ}\ \mathrm{fus}\ )\mathrm{plastic} \quad (1)$$

$$\Delta Q\ Reactor = qm\ in \quad (2)$$

The change in heat in the reactor was calculated in a similar way using equation (3) and
Equation (4) below:

$$\Delta \mathrm{q\ Reactor} = (\mathrm{C\ p}\ \Delta \mathrm{T} + \Delta \mathrm{h}^{\circ}\ \mathrm{vap}\ )\mathrm{plastic} + (\mathrm{C\ p}\ \Delta \mathrm{T} + \Delta \mathrm{h}^{\circ}\ \mathrm{vap}\ )oil \quad (3)$$

$$\Delta \mathrm{Q\ Reactor} = \mathrm{q\ Reactor\ (m\ in} + \mathrm{m\ Feedback\ Oil\ )} \quad (4)$$

Volumetric flow rate calculations

We needed to know the density, linear thermal expansion coefficient, and temperature change of the molten plastic as it entered the reactor first. To establish the needed system size, the volumetric flow rate within the reactor and the pipe must be understood. As has been demonstrated, the presence of heat changes the volume of numerous substances. Because of this occurrence, the linear thermal expansion coefficient of each material must be established. This value can be used to compute the new density of a substance. The volume control is conveniently positioned just around the corner from here.

$$\rho\ \mathrm{Reactor,out} = \rho\ \mathrm{Reactor,in} = \frac{\rho \mathrm{Melted\ plastic}}{1 + \alpha(\mathrm{T\ new} - \mathrm{T\ m.p.})} \quad (5)$$

Here, equation (5) above is used to find the density of the plastic at the inlet of the reactor; however, this equation can be used to find the viscosity at any point within the reactor that sees solid or liquid flow. The reactor output density was found using the ideal gas law and crude oil and hydrocarbon output as the gas. Using the mass flow rate and densities found using the method above, the volume flow rate can be calculated using the following equation (6):

$$\mathrm{V} = \frac{\rho \mathrm{m}}{\mathrm{t}} \quad (6)$$

From this point, the flow rate was converted to standard cubic feet per minute (SCFM).

The Plastic Densifier CAD model

To develop 2D design models, AutoCAD was used. Because of the risky nature of the densifier and the group's inexperience with the system's operation, all parts of the design were examined and approved by all parties before manufacturing begins.

RESULTS AND DISCUSSION

Analysis of Findings

The whole design of the plastic pyrolysis plant took three steps: preliminary heat calculations, CAD design, fabrication, testing, and instrumentation. The heat calculations were performed to record temperature, mass flow rate, and volumetric flow rate at various places in the system. The process flow diagram and instrumentation diagram were created using these values.

Economic and environmental impact

The design of this plastic pyrolysis system has environmental and economic ramifications for Nigeria. Global plastic manufacturing is expected to have quadrupled from 348 million tons in 2017 by 2050. (Qureshi et al., 2020). As our society consumes more and more plastic, new technology is required to lessen the environmental impact of plastic manufacture. Plastic garbage is currently mechanically recycled, disposed of in landfills, or burned to generate electricity. Mechanical recycling of plastic trash, on the other hand, requires homogeneous, high-quality materials that have already been sorted and washed. Heterogeneous and multi-layered plastics can be recycled because waste gases are recovered during the pyrolysis process. According to a study conducted in Finland utilizing life cycle assessment (LCA), the carbon footprint of plastic landfilling can be decreased by up to 67 percent to 76 percent using a mix of mechanical and chemical recycling (Qureshi et al., 2020).

The disadvantage of pyrolysis is that it emits CO_2 into the atmosphere. CO_2 scrubbers can be used to reduce CO_2 emissions. Despite this, pyrolysis emits only one-third of the CO_2 emitted by a typical landfill. Pyrolysis, on the other hand, does not produce toxic dioxins, which are released when plastics are burned when they are cremated. There are various advantages to increasing the petrochemical and plastic industries by adopting the plastic pyrolysis method. However, the legislative component is a big impediment to the commercialization of this type of technology in Nigeria.

The broad policy umbrella of environmental protection encompasses environmental protection, product safety, and the circular economy. These laws and regulations differ from one country to the next. Despite the fact that plastic pyrolysis technology has been perfected and manufactured, it will take some time before it is

commercialized and widely utilized. This device is used to convert approximately 1,200 tons of plastic waste into various materials each year. It is the first time in our area that a pyrolysis unit has been utilized to handle plastic garbage. This will have a considerable influence on plastic trash disposal, but it will not be enough to fix the problem. A profitable technique of disposing of plastic will be devised in the expectation that the pilot plant's success will lead to the building of more plastic pyrolysis plants. Profitability is obtained from the materials produced and the disposal of plastic at this operation.

Shortcomings

As the project developed, the true magnitude of the machine became clear. To fulfill the goal of designing the reactor, the project's scope had to be reduced several times. Certain elements of the reactor were finished over time, but others were ignored despite their evident importance.

Conclusion

The initial heat estimates were required as a baseline to determine how this machine would run and if it was viable while designing a pilot-scale pyrolysis machine. Following the establishment of these calculations, the process flow diagram, fabrication, and instrumentation were produced as a schematic depiction of the pyrolysis machine design. The CAD model was then completed while simultaneously contacting companies to locate parts and instrumentation for the fabrication of this pyrolysis machine. Waste disposal is one of Nigeria's most pressing issues. Such garbage is composed of polymers and plastics, which have been found to be challenging to treat in studies. Plastic trash disposal is becoming a global issue as a result of industrialization and demographic expansion. One important reason contributing to Nigeria's insufficient waste management is the country's increased population density. Plastic is used as a feedstock by plastic densifiers to create building materials such as pavers, solar roof tiles, and fence posts. As a result, the densifier was created to process and recover non-rigid plastic material from industrial trash, residences, and washing lines.

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