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THERMOCHEMICAL VOLATILIZATION OF HETEROGENEOUS FOOD WASTE: FROM PLATE TO PROPANE

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ABSTRACT

Food waste is a serious global environmental problem that contributes to landfill buildup, greenhouse gas emissions, and wasteful resource use. An efficient and sustainable method for turning heterogeneous food waste into useful fuels like propane and other energy-rich products is thermochemical valorization. In this process, high-temperature conversion methods like gasification and pyrolysis are applied to mixed organic food leftovers from homes, restaurants, and food enterprises. Complex organic materials are broken down by

these thermochemical processes into simpler substances like syngas, bio-oil, and light hydrocarbons, which can be used. Thermochemical valorization helps minimize methane emissions from the decomposition of organic waste and lessens the load on landfills by converting food waste into renewable energy sources, additionally, by encouraging sustainable waste management techniques and recovering energy from waste, products, this technology advances the idea of a circular economy. All things considered, turning food waste "from plate to propane" is a creative way to combat environmental contamination and the rising demand for alternative energy sources worldwide.

KEYWORDS: Greenhouse gas emissions, Thermochemical valorization, Heterogeneous food waste, Pyrolysis.

INTRODUCTION

One of the most urgent environmental and socioeconomic issues facing the globe today is food waste [5, 20]. The amount of food waste produced by homes, restaurants, hotels, the food processing industry, and agricultural operations has greatly increased due to rapid urbanization, population development, and shifting consumption patterns [8, 16, 20].A significant amount of this trash is dumped in open dumping sites or landfills, which has detrimental effects on the environment, including greenhouse gas emissions, contaminated soil and water, and wasteful use of natural resources [22, 24]. Methane, a powerful greenhouse gas that greatly contributes to climate change, is produced when food waste breaks down in landfills under anaerobic conditions [10, 19]. As a result, the creation of sustainable methods for handling and using food waste has grown in importance as a field of study in biotechnology and environmental science [6, 21]. Thermochemical valorization of heterogeneous food waste, which focuses on turning waste materials into useful energy products like propane and other hydrocarbon fuels, is one promising strategy to address this issue [25, 30]. The term "thermochemical valorization" describes a set of procedures that transform organic materials into valuable products by using pressure, heat, and chemical reactions [11, 25]. Thermochemical treatments work at higher temperatures and can quickly transform complex organic waste into a variety of energy-rich molecules, in contrast to biological treatment techniques like composting and anaerobic digestion [7, 25]. Heterogeneous food waste is a difficult but extremely desirable feedstock for energy generation since it contains a variety of carbohydrates, proteins, lipids, fibers, and moisture [14, 23]. The concept of transforming waste "from plate to propane" highlights the potential of converting everyday food residues into clean and useful fuel through advanced thermochemical technologies [21, 34]. Several thermochemical processes are commonly used for the conversion of food waste, including pyrolysis, gasification, and hydrothermal liquefaction [12, 25, 27]. Pyrolysis is a thermal decomposition process that occurs in the absence of oxygen, typically at temperatures ranging from 300℃ to 700℃ [13, 32]. During pyrolysis, complex organic compounds present in food waste break down into smaller molecules, producing three main products: bio-oil, bio-char, and syngas [13, 28]. Bio-oil is a liquid fuel that can be further refined and upgraded to produce hydrocarbons similar to conventional fuels [28, 31]. Bio-char is a carbon-rich solid that can be used as a soil amendment or carbon sequestration material [29]. syngas, which is mostly made up of hydrogen, carbon monoxide, methane, and other light gases, can be processed further to create fuels like propane or utilized to generate heat and electricity [30, 31]. Another significant thermochemical method for turning organic waste into energy is gasification [26, 30]. This process involves partially oxidizing food waste at temperatures, often between 700℃ and 1000℃, with a little amount of steam or oxygen present [26, 30]. Through this process, organic molecules are transformed into synthesis gas, also referred to as syngas, a flammable gas mixture [26]. The main components of syngas are hydrogen and carbon monoxide, which can be utilized as feedstock in a variety of chemical processes to create hydrocarbons and liquid fuels [30, 31]. Syngas may be transformed into fuels like methane, propane, and other light hydrocarbons by catalytic upgrading procedures [18, 31]. These fuels can be utilized as alternative energy sources for industrial, transportation, and cooking uses [24, 30]. Another interesting method for turning food waste into biofuels is hydrothermal liquefaction, especially as food waste frequently has a high moisture content [9, 27]. In contrast to pyrolysis and gasification takes place in water at high pressure and temperatures (250-374℃) [9, 27]. In these circumstance, water serves as reaction medium that makes it easier for complex organic molecules to break down into smaller parts, resulting in the production of bio crude oil, gaseous products and watery byproducts [12, 27]. Through catalytic refining, the bio crude oil produced by this process can be improved to create hydrocarbon fuels like propane, gasoline, and molecules that resemble diesel [18, 31]. Because this technology does not require energy-intensive drying procedures, it is especially beneficial for processing wet biomass, in order to transform intermediate products from thermochemical processes into superior fuels, catalytic upgrading is essential [18, 31]. Zeolites and metal-based catalysts are examples of catalysts that boost fuel yield, increase reaction efficiency, and encourage the production of desired hydrocarbons like propane [18, 28]. These catalysts help break down complex organic compounds into simpler molecules that can be used as fuels through processing including hydrogenation, cracking and reforming [18, 31]. It is possible to efficiently produce clean, renewable energy from food waste by combining catalytic procedures with thermochemical conversion technology [30, 31]. Food waste can be thermochemical valued for a number of financial and environmental advantages. First, it offers a practical way to cut down on the quantity of waste dumped in landfills, which minimizes land consumption and pollution [22, 33]. Second by stopping the production of methane during the breakdown of trash, it helps lower greenhouse gas emissions [10, 19]. Third, it encourages the generation of renewable energy, which lessens reliance on fossil fuels and advanced energy sustainability [24, 35]. Furthermore, turning food waste into useful fuels open doors for resource recovery and advances the creation of a circular economy, where waste products are recycled into useful resources [21, 34]. The large-scale application of thermochemical technology for food waste conversion faces a number of obstacles despite its many benefits. The fact that the food waste is diverse in terms of composition, moisture content and energy value is one of the main problems [14, 23]. The effectiveness and consistency of thermochemical processes may be impacted by this variability [25, 30]. The high capital costs of installing and running sophisticated thermochemical conversion devices present another difficulty [30]. Additionally, to increase fuel yield and lower process costs, effective and long-lasting catalysts must be developed [18, 31]. By creating better reacting designs, cutting-edge catalysts, and integrated waste management systems, researchers are actively attempting to overcome these issues [25, 31]. The successful use of food waste valorization strategies depends on efficient waste segregation and collection systems in addition to technical advancements [22, 33]. The efficiency of thermochemical processes is increased and feedstock quality is improved when organic waste is properly separated from other waste kinds [22]. The adoption of waste-to-energy technology and the promotion of sustainable waste management techniques are also greatly aided by government laws and public awareness [16, 20]. The idea of turning food waste “from plate to propane” is revolutionary method of managing waste and producing renewable energy [21, 34]. Common meal leftovers can be converted into useful hydrocarbon fuels that can be utilized for a variety of energy purposes by using thermochemical conversion processes [30, 31]. This strategy helps the world move towards low-carbon and sustainable energy systems while also addressing the growing issue of food waste [24, 35]. In conclusion, a valuable method for turning organic waste into valuable fuels like propane is the thermochemical valorization of heterogeneous food waste [25, 30]. Complex organic materials can be effectively converted into energy-rich products by procedures including hydrothermal liquefaction, gasification and pyrolysis [13, 26, 27].This strategy has the potential to significantly contribute to sustainable waste management, the production of renewable energy, and environment protection with further study, technological advancements and supportive legislation [21, 33]. Building a more resource-efficient and sustainable future will need the development and application of such waste-to-energy technology [24, 35].

Fig.no.01.

NEED FOR STUDYING

1. INCREASING FOOD WASTE PROBLEMS

The production of food waste has significantly increase as a result of urbanization, population growth, and lifestyle changes [5, 20]. At several phases, including production, processing, shipping, retail, and domestic consumption, large amounts of food are wasted [5, 8]. Typically, this garbage ends up landfills or other disposal sites, which have negative effects on the environment and the economy [22, 33]. Finding sustainable ways to transform this trash into valuable energy products like propane is made easier by researching the thermochemical valorization of heterogeneous food waste [25, 30]. Understanding this subject can help industry and researches create effective methods to manage food waste, lessens the impact on the environment, and turn rejected food products into useful resources rather than pointless garbage [21, 34].

2. ENVIRONMNETAL PROTECTION

When food waste is disposed in landfills, greenhouse gases- particularly methane-are produced, which greatly exacerbates climate change and global warming [10, 19]. In addition to contaminating land and water, improper waste management draws pests and spreads dangerous microbes [22]. Researching thermochemical valorization aids in the development of systems that use high-temperature processes to turn organic food waste into fuels. This lessens hazardous pollutants and the quantity of waste dumped in landfills [25, 30]. This method promotes ecological balance and environmental conservation by turning waste into energy. Therefore, it is crucial to comprehend this subject in order to promote ecologically friendly waste management techniques and reduce pollution [21, 24].

3. RENEWABLE ENERGY PRODUCTION

Alternative energy sources are now necessary due to growing demand for energy and the depletion of fossil resources [24, 35]. Organic substances included in food waste, such as proteins, lipids and carbohydrates, contains substantial amounts of chemical energy [14, 23]. This energy can be transformed into useful fuels like propane, bio-oil and syngas, via thermochemical processes like gasification and pyrolysis [13, 26]. Researchers can better understand how waste materials can be converted into renewable energy sources by studying this topic. This solves the issue of food waste also lowering reliance on fossil fuels and offering a sustainable way to generate clean electricity [24, 30].

4. SUSTAINABLE WASTE MANAGEMENT

Because they occupy land, release toxic gasses, and damage natural resources, traditional waste disposal techniques like landfilling and open dumping are not long-term viable [22, 33]. Food waste can be transformed into usable fuels and chemicals using thermochemical valorization, a contemporary waste-to-energy solution [25, 30]. Learning about this subject makes it easier to comprehend how cutting-edge technologies can be applied to effectively manage organic waste. This strategy promotes the idea of a circular economy, in which waste resources are recycled and repurposed to make new goods [21, 34]. Scientists and politicians can create more sustainable waste management methods by understanding about thermochemical conversion.

5. EFFICIENT RESOURCE UTILIZATION

Food waste contains useful organic elements including starch, sugars, lipids, and proteins that can be used as energy sources, making it more than just worthless trash [14, 23]. Thermochemical technology can transform these materials into fuels and other useful products rather than throwing them away [25]. Understanding how the resources can be effectively used through high-temperature chemical processes is made easier by studying this subject. This decreases the waste of organic resources that are rich in energy and increases resource efficiency [21, 24]. By turning waste materials into commercially viable goods, efficient use of food waste also promotes sustainable development, lessens in impact on the environmental and conserves natural resources.

6. TECHNOLOGICAL ADVANCEMENTS IN WASTE-TO-ENERGY

Advanced technologies including hydrothermal liquefaction, gasification and pyrolysis are used in thermochemical valorization [12, 26, 27].To turn organic waste into energy products, these processes need certain tools, catalysts, and regulated reaction conditions [30, 31]. Researches can better comprehend the benefits, drawbacks, and operating principles of various technologies by studying this subject. Additionally, it promotes innovation in process optimization, catalysts development, and reactor design [25, 31]. Scientists and engineers can increase the effectiveness and scalability of waste-to-energy systems by learning more about this field. This advanced technology and aids in the development of workable solution of turning massive amount of food waste into fuel.

7. ECONOMIC BENEFITS

The collection, transportation and disposal of food waste typically come at the high expense [33]. This waste can be transformed into useful fuels and chemicals through thermochemical valorization, opening up business prospects [24, 30]. Researching this subject aids in finding strategies to lower waste management expenses while producing energy and making money. Businesses can reduce their reliance on costly fossil fuels by using waste-derived fuels as alternative energy sources. Furthermore, the construction of waste-to-energy facilities can boost employment and economic expansion [33]. Therefore, comprehending the thermochemical conversion of food waste promotes economic growth in addition to environmental benefits.

8. FUTURE ENERGY SECURITY

Fossil fuel sources are steadily running out as the world`s energy needs are rising quickly [24, 35]. The necessity of creating renewable and sustainable energy sources id highlighted by this circumstance. Food waste is the readily available and renewable feedstock that may be used in thermochemical processes to produce fuels like syngas and propane [25, 30]. Researching this subject aids in the investigation of creative ways to generate energy sources, this promoted long-term energy security. Waste- to-energy technology may be crucial in the future for sustainability supplying the world`s energy demands [24].

Fig no.02.

SUITABLE METHODS

- **PYROLYSYS**

Pyrolysis is one of the most viable thermochemical techniques for converting heterogeneous food waste into useable fuels. This process involves heating organic waste to temperatures between 300 and 700℃ without the presence of oxygen [13, 32]. Heat breaks down complex organic compounds found in food waste into simpler products like syngas, bio char, bio-oil can be further refined to yield propane and other hydrocarbons [13, 28]. Pyrolysis is suitable for mixed food waste because it can efficiently treat a range of organic components. This method reduces waste volume and produces useful energy products, making it an effective technology for sustainable waste-to-energy conversion.

- **GASIFICATION**

Another efficient thermochemical technique for turning food waste into gasses rich in energy is gasification. This method involves heating food waste to extremely high temperature (700-1000°C) with little oxygen or steam [26, 30]. Hydrogen, carbon monoxide, methane and other light gases make up the majority of synthesis gas (syngas), which is created when the organic components decomposes. Through catalytic reactions, this syngas can be transformed into fuels like propane and methanol or utilized to generate energy [30, 31]. Because it effectively turns massive amount of garbage into clean fuel while lowering landfill waste and environmental damage, gasification is seen as a practical technique.

- **HYDROTHERMAL LIQUEFACTION (HTL)**

Since most food remnants have a higher moisture content, hydrothermal liquefaction is especially appropriate for food waste. This process uses high temperatures (250-374°C) and high pressure in the presence of water to turn wet biomass into bio crude oil [9, 27]. Hydrothermal liquefaction lowers energy and processing costs because it doesn't require drying the feedstock like other thermochemical processes do. Fuels like propane, gasoline, and compounds that resemble diesel can be made by further refining the bio crude oil [18, 27]. This method have great potential for large-scale waste-to-energy applications and is effective at turning heterogeneous food waste into liquid fuels.

- **CATALYTIC UPGRADING**

An essential stage in raising the caliber of fuels generated by thermochemical conversion processes is catalytic upgrading [18, 31]. This process transforms intermediate products like syngas or bio oil into lighter hydrocarbons like propane using catalysts like zeolites or metal catalysts. In order to increase fuel production and energy efficiency, catalysts encourage chemical reactions like hydrogenation, reforming, and cracking [18, 28]. This procedure is crucial because raw materials from gasification or pyrolysis frequently need additional processing to turn into useful fuels. Thus catalytic upgrading is essential for turning food waste into valuable energy products.

- **TORREFACTION**

A gentle thermochemical process called torrefaction is used to enhance biomass`s fuel qualities. This method involves food waste without oxygen to temperature between 200 and 300°C [29]. By eliminating moisture and volatile substances, this process creates a solid fuel that is more energy-dense and simpler to transport and store [29]. In order to create fuels like propane, torrefied biomass can be utilized as a feedstock for additional thermochemical processes like gasification or pyrolysis. Torrefaction helps transform heterogeneous food waste into more stable and increases the overall efficiency of waste-to-energy systems.

INNOVATION APPLI ATION OPPORTUNITY

- **WASTE-TO-ENERGY PRODUCTION**

Technologies for thermochemical valorization offer creative way to turn food waste into renewable energy. Heterogeneous food waste can be converted into fuels like propane, syngas, and bio oil using procedures like pyrolysis and gasification [25, 30]. These fuels can be utilized for residential energy demands, industrial heating, and the production of electricity. Large amounts of food waste can be effectively managed by integrating waste-to-energy technologies into municipal waste management facilities. This application produces sustainable energy while simultaneously reducing landfill accumulation [24, 25]. Communities can address environmental issues connected to organic waste management and increase energy efficiency by using food waste as a resource.

- **SUSTAINABLE TRANSPORTATION FUELS**

The creation of alternate fuels for transportation in another creative use. Food waste can be transformed into hydrocarbons, such as propane and other liquid fuels, for use in automobiles by thermochemical processes [18, 31]. These fuels have the potential to be more environmentally friendly than traditional fuels derived from petroleum. Utilizing fuels made from waste helps lower greenhouse gas emission and lessens reliance on fossil fuels [24]. By providing renewable fuels for buses, trucks, and industrial vehicles, waste-to-fuel technologies have the potential to enhance sustainable transportation systems in the future, improving energy sustainability and creating cleaner urban environments.

- **BIOREFINERY INTEGRATION**

Modern bio refineries, which combine various conversion processes to create a variety of valuable goods, can incorporate food waste valorization. Food waste can be transformed into fuels like propane in these systems like thermochemical processes, and other component can be utilized to create chemicals, fertilizers, or biomaterials [21, 34]. This integrated strategy reduces waste production while optimizing resource consumption. With renewable biomass feedstock in place of fossil fuels, bio refineries, can function similarly to petroleum refineries.

The creation of bio refineries based on food waste offers a novel way to support sustainable industrial practices and turn organic waste into goods with additional value.

- **SMART WASTE MANAGEMENT SYSTEMS**

Smart waste management systems in cities can be integrated thermochemical conversion technology. Food waste can be identified and separated for thermochemical processing using sophisticated trash collecting and sorting technology [22, 33]. Instead of disposing of organic waste into landfills, this enables municipalities to turn it into valuable energy. Additionally, intelligent waste management systems can improve waste processing facilities and keep an eye on trash generation. These developments encourage ecologically friendly trash treatment methods and increase the effectiveness of garbage handling. Cities may create sustainable systems that generate renewable energy and lessen pollution by incorporating thermochemical technologies into their infrastructure.

- **INDUSTRIAL FUEL REPLACEMENT**

Large amount of energy are needed by industries for processing, manufacturing, and heating. Alternative industrial fuels include syngas and propane, which are created through the thermochemical valorization of food waste. In boilers, furnaces, and power plants, these waste-derived fuels can take the place of traditional fossil fuels [24, 30]. Industries and lower carbon emissions and increase sustainability by using renewable fuels. Additionally, businesses that produce food waste, such restaurants and food processing facilities. Can employ thermochemical technology to turn their own trash into energy, resulting in a closed-loop systems that lowers operating costs and increases resource efficiency.

ADVANCEMENT

Thermochemical technology used to transform heterogeneous food waste into useful fuels like propane, syngas and bio oil have advanced significantly in recent years. Heat transfer efficiency and reaction control during thermochemical processes have been improved by improved reactor designs, such as fluidized bed reactors and microwave-assisted systems [25, 30]. Higher conversion rates and improved gasoline quality are made possible by these advancements. With the creation of zeolite and metal- based catalysts that boost the yield of light hydrocarbons like propane, catalytic upgrading techniques have also evolved significantly [18, 31].

Additionally, temperature, pressure, and reaction conditions are now more precisely co trolled thanks to automation technology and contemporary 1monitoring systems. Process optimization and operational efficiency have been further enhanced by the integration of machine leaning and artificial intelligence [30]. The creation of hydrothermal liquefaction devices, which can treat wet food waste without the need of drying and use less energy, is another development. In order to optimize resource recovery, researchers are also investigating hybrid systems that integrate biological and thermochemical processes. Large scale waste-to energy applications are now possible thanks to these technological advancements that have improved thermochemical valorization`s efficiency, viability and environmental friendly.

IMPACT

Waste management techniques, energy production, and environmental sustainability are all significantly impacted by the thermochemical valorization of heterogeneous food waste. The decrease in landfill garbage is one of the most significant environmental advantages. Large volumes of food waste are usually dumped in landfills, where they breakdown and release methane, a potent greenhouse gas. Thermochemical methods reduce greenhouse gas emission and environmental degradation by turning food waste into fuels like syngas, bio oil, and propane [10, 22]. Additionally, this strategy encourage the generation renewable energy, which can lessen reliance on fossil fuels and improve energy security [24, 35]. Waste-to-energy technologies have the potential to generate employment opportunities and new enterprises in the waste management and renewable energy sectors [33]. They help lower the expenses related to landfills upkeep and waste removal. Socially, thermochemical valorization enables communities to see waste as a useful resource rather than an issue and raises awareness of sustainable resource usage. Overall this technology has an influence that goes beyond trash management because it helps mitigate climate change, generate renewable energy, and create a circular economy that effectively reuse waste materials.

DISADVANTAGES

Thermochemical valorization has several advantages, but its widespread application is constrained by a number of drawbacks and difficulties. The large initial outlay needed to setup thermochemical conversion plants is one of the primary disadvantages [30]. High-temperature reactors, catalysts and sophisticated control systems are example of equipment that can be costly to install and operate. The diverse makeup of food waste presents another difficulty. Food waste can impact effectiveness and consistency of thermochemical processes because it contains different levels of moisture, lipids, proteins, and carbs [14, 23]. Additionally, some processes need for very high temperatures, which raises operative expenses and energy usage. Furthermore, impurities like metals, plastics, and inorganic components in mixed waste streams may hinder the conversion process and lower than the quality of the final product [25]. Therefore, prior to thermochemical treatment, proper waste segregation and pretreatment are required. Technological complexity is another problem, since these systems need sophisticated monitoring tools and trained staff to operate. These drawbacks emphasize the necessity of ongoing study and development to raise the effectiveness, and scalability of thermochemical methods for the conversion of food waste.

ETHICAL ISSUE

The development and application of food waste valorization technologies are heavily influenced by ethical considerations. A crucial ethical concern is striking a balance between efforts to prevent food waste at the source and waste-to-energy production [5, 20]. Although it is advantageous to waste food waste into fuel, efforts to reduce needless food lose or enhance food distribution network to combat hunger should not be discouraged. Environmental safety is another ethical issue. To prevent the release of hazardous emissions, pollutants, or toxic byproducts into the environment, thermochemical processes need to be carefully controlled [24]. Concerns regarding public health and air pollution may also exist in communities close to waste-to-waste energy operations. Therefore it is crucial to be transparent in project planning, environmental monitoring, and policy execution. Responsible resource use and equitable access to the advantages of renewable energy technology are further ethical factors. In order to address the global problem of food waste, governments, businesses, and researchers must make sure that thermochemical technologies are applied in ways that safeguard public health, preserve environmental sustainability, and benefit society [21].

FUTURE SCOPE

Given the growing demand for sustainable energy and better waste management techniques, the potential thermochemical valorization of food waste is quite promising. It is anticipated that future research will concentrate on creating more effective catalysts and sophisticated reactor designs can boost fuel yield and lower energy usage. Technological advancements in digital monitoring systems and artificial intelligence have the potential to enhance operational efficiency and optimize thermochemical processes [25, 31]. Overall resource recovery from food waste may be improved by combining thermochemical technology with other waste treatment techniques like anaerobic digestion or biochemical conversion [24]. As governments support renewable energy initiatives and tighten waste management rules, large-scale commercial waste-to-energy plants are expected to proliferate [16, 33]. Additionally, cleaner feedstock for thermochemical processing will be made possible by enhanced waste segregation and collection systems. To further boost food waste`s economic value, researchers are looking into a greater variety of useful chemicals and fuels. Thermochemical valorization has the potential to be a major solution for the production of renewable energy and the management of food waste worldwide with further technology advancements and supportive regulations

CONCLUSION

An inventive and long lasting answer to the expanding issue of food waste management is provided by thermochemical valorization of heterogeneous food waste. Organic waste materials can be transformed into useful fuels like propane, bio-oil, and syngas by procedures including pyrolysis, gasification, and hydrothermal liquefaction. This strategy minimizes greenhouse gas emission, lessens the quantity of garbage dumped in landfills, and promotes the generation of renewable energy. Thermochemical technologies supports sustainable resource use and the growth of the circular economy by converting waste into valuable resources. Ongoing research and technology developments are assisting in overcoming obstacles such high stock, feedstock variability, and technological complexity. Thermochemical conversion is becoming more economically feasible and efficient because to improved catalysts, sophisticated reactors, and integrated waste management systems. The conversion of food waste “from plate to propane” is a viable technique for attaining sustainable growth and environmental protection in the future, as worries about climate change, waste management, and energy security continue to grow globally.

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