Biochar an Alternate Renewable Resource for the Future

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Introduction

In the present era, adopting eco-friendly practices is crucial, especially due to the depletion of finite natural resources. A recent discovery is that waste from farms, which was once seen as useless, can actually help reduce greenhouse gases and is a step towards being carbon neutral. The problem lies in finding practical ways to manage this massive quantity of farm waste. Traditionally, crop leftovers have often been burned in open fields, but this practice contributes significantly to greenhouse gas emissions and air pollution. The Ministry of New and Renewable Energy (MNRE) of India estimated that crop residues are produced in India annually at a rate of 500 million tons (Mt). Therefore, there is still a surplus of 140 million tons, of which 92 million tons are burned annually in India (according to NPMCR (National Policy for Management of Crop Residues, 2019).

Fortunately, an innovative approach involves converting agricultural waste into a valuable material called biochar through a thermochemical process known as pyrolysis (Safarian, 2023). Notably, the calorific value (HHV) of crop residues ranges between 12.16 and 20.53 MJ/kg, which is relatively low compared to the HHV range of 27.39 to 32.60 MJ/kg for biochar (Boumanchar et.al, 2017). This higher energy density makes biochar a more attractive fuel source and when applied to farmlands, biochar can combat global warming in two main ways: Firstly, it acts as a carbon sink, capturing carbon dioxide from the air and preventing it from exacerbating the greenhouse effect. Secondly, it helps reduce the amount of greenhouse gases released from the soil itself.

By transforming the polluting farm waste into biochar through pyrolysis and utilizing it on farmlands, we can effectively address the dual challenges of resource scarcity and greenhouse gas emissions (Safarian, 2023). This environmentally-friendly approach presents a viable solution for sustainable farming practices while simultaneously managing the massive quantities of crop residues generated in India.

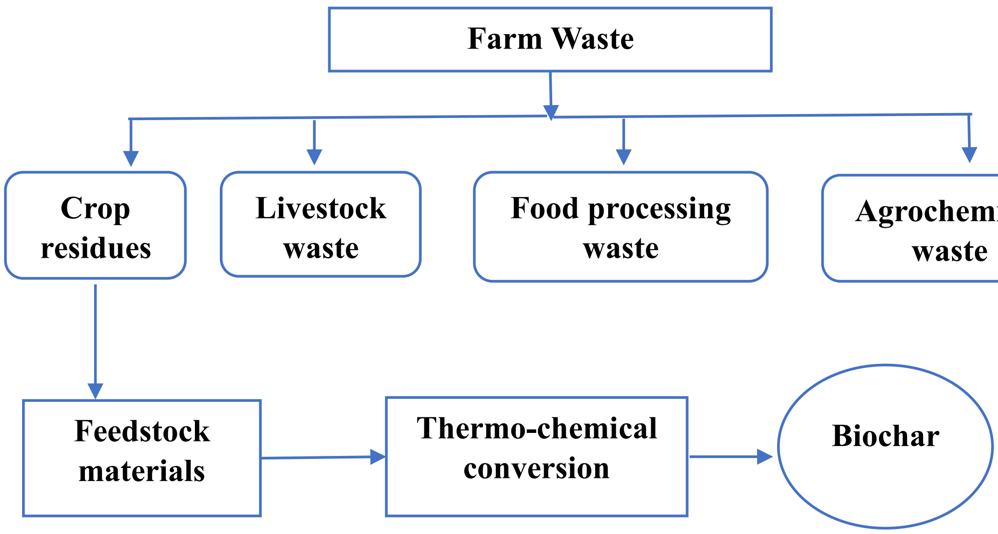

Fig.1. Flow chart for production of biochar from farm waste

What is biochar?

"Biochar is a fine-grained, carbon-rich, porous product remaining after plant biomass has been subjected to thermochemical conversion process (Slow pyrolysis) at temperatures 350-600°C in an environment with little or no oxygen" (Amonette and Joseph, 2009).

Biochar is a solid material obtained from thermochemical conversion of biomass in an oxygen limited environment." (IBI,2012).

The key thing about biochar is that it is very rich in carbon and has a stable structure that doesn't break down easily. When added to soil, this stable carbon structure acts like a trap, preventing the quick release of carbon dioxide gas from the original organic material as it decomposes.

Fig. 2. Biochar obtained after thermochemical conversion of biomass

Biochar can be produced at a commercial scale from different agricultural crop residues including rice straw, wheat straw, groundnut shells, rice husk, soybean straw etc. whereas switch grass, wood and bagasse from the sugarcane industry are also utilized for production of biochar.

Biomass consists of hemicellulose, cellulose, and lignin together with trace number of extractives and minerals. Variable biochar yield is obtained due to difference in composition of cellulose, hemicellulose and lignin in different biomass species. Feedstock with high lignin content generates high yields of biochar when pyrolyzed at temperatures of approximately 500˚C (Demirdas et al, 2006 and Fushimi et al, 2003).

Techniques used for biochar production

Biochar is an incredibly versatile material that can be produced through various thermochemical conversion processes applied to agricultural crop residues. The first step is to carefully select the appropriate crop residue feedstock, which could include straws from cereal crops like rice, wheat, and corn, or residues from other crops like sugarcane bagasse, coconut shells/husks, groundnut shells, etc. Once the crop residue is collected and prepared, the next crucial step is choosing the right production technology based on factors like desired biochar properties, scale of operation, and economic feasibility. Several sustainable technologies are available as shown in below flow diagram. These technologies are utilized at domestic level for small scale biochar production by the farmer for agriculture utilization as well as at large scale production of biochar for energy production (Patel et.al, 2023).

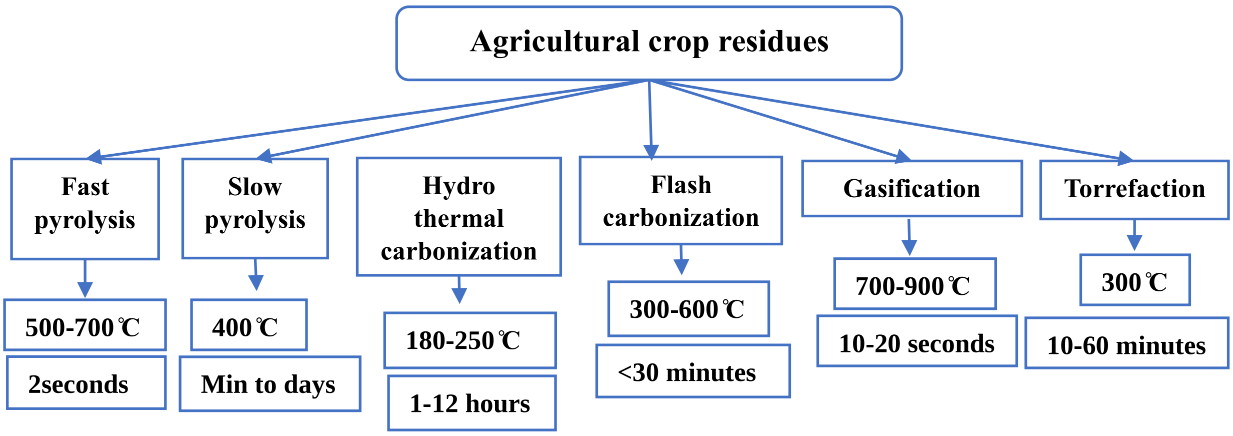

Fig.3. Different technologies used for production of biochar from agricultural crop residues (Sharma et.al, 2024).

Different techniques, including batch and continuous processes, are used along with various technologies for the production of biochar they are mention below:

1. Batch Process (Slow Pyrolysis):

- This involves the direct heating of biomass in an oxygen-limited environment, typically at slower heating rates and lower temperatures (around 300-500˚C).
- The biomass is loaded into a closed reactor or retort, which is then heated externally.
- The slow heating rates and longer residence times favor the formation of solid biochar as the main product.
- Gases and small amounts of liquid products (bio-oil) are also produced as by-products.
- Batch processes are suitable for smaller-scale operations and allow for better control over the pyrolysis conditions.
- Examples include traditional kilns, drum kilns, and batch retort reactors.

2. Continuous Process (Fast Pyrolysis):

- This involves the rapid heating of biomass particles in the absence of oxygen, typically at higher temperatures (around 500-650°C).
- The biomass is continuously fed into a reactor, where it is indirectly heated by hot surfaces or heat carriers.
- The rapid heating rates and shorter vapor residence times favor the formation of bio-oil as the main product.
- Biochar and non-condensable gases (syngas) are produced as by-products.
- Continuous processes are suitable for larger-scale operations and can achieve higher throughputs.

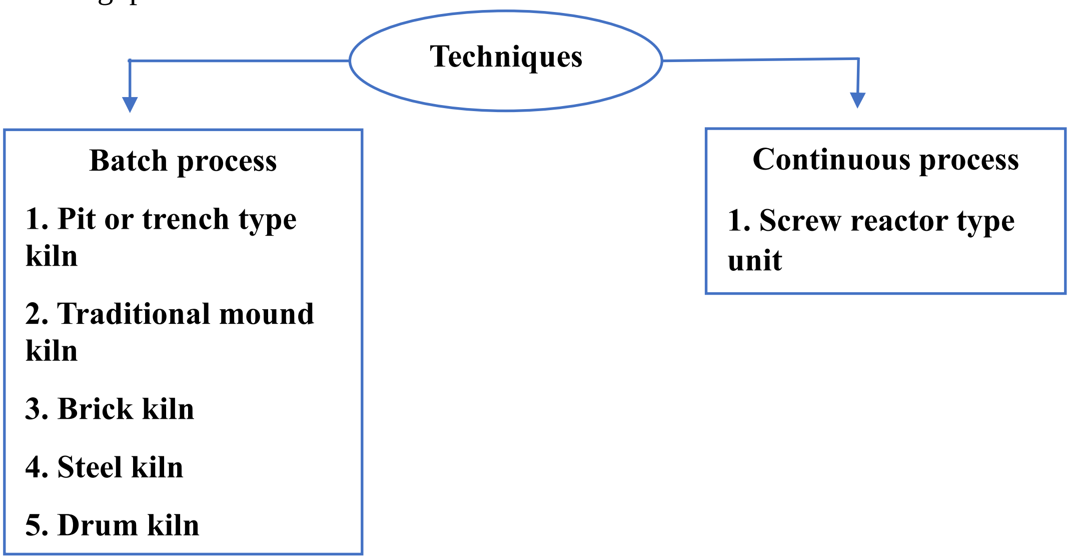

Fig.4. List outed different techniques used for the production of biochar

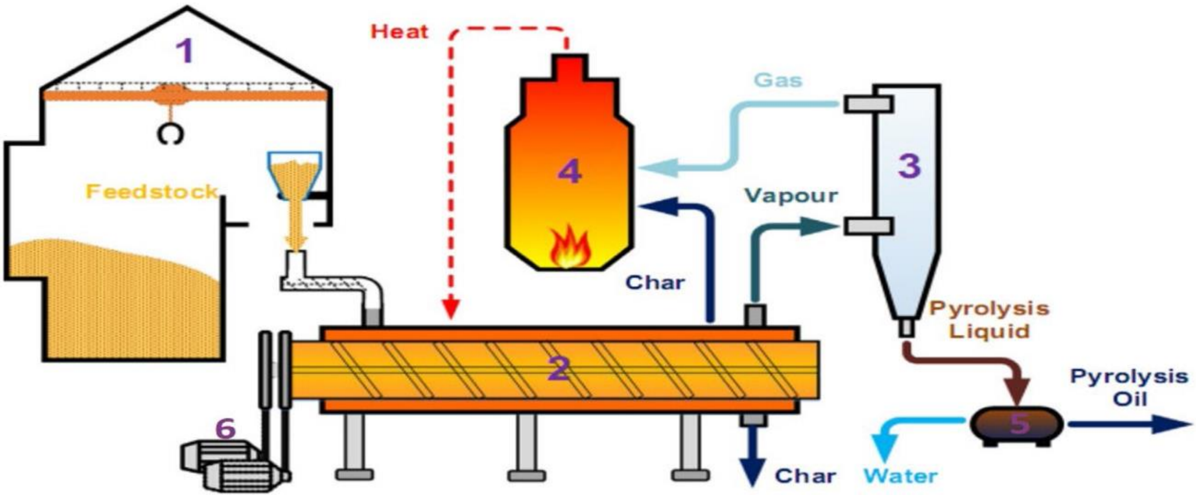

Fig.5. Screw-based pyrolyzer, 1. Feeding system, 2. Reactor, 3. Condenser, 4. Char-gas combustor, 5. Liquid separator, 6. Motors (Yang et al., 2017)

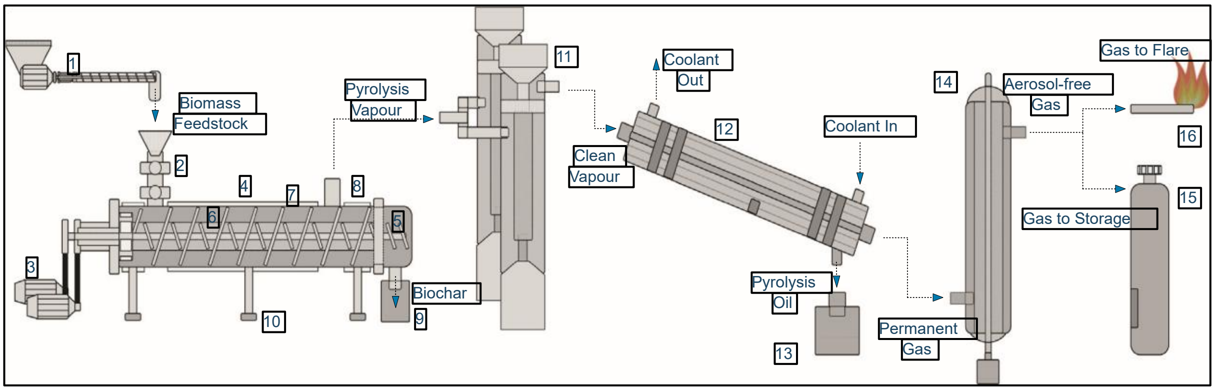

Fig.6. Continuous pyrolysis system. (1) Feeding system; (2) feed inlet; (3) electric motors; (4) the Pyro former; (5) inner screw; (6) outer screw; (7) external heating jackets; (8) vapour outlet; (9) char pot; (10) stands; (11) hot gas filter; (12) shell and tube condenser; (13) oil vessel; (14) electrostatic precipitator; (15) gas vessel; (16) gas flare (Yang et al., 2017).

Utilization of Biochar

The biochar produced from the agricultural crop residues can be used for different purposes as listed below (Awogbemi and Von Kallon, 2023):

i. **Soil Amendment:**

Biochar can enhance the cation exchange capacity of soils, which helps in retaining essential plant nutrients. Its porous structure improves soil aeration and water-holding capacity. Biochar can also act as a buffer in soil acidity, creating a more favorable environment for plant growth and microbial activity.

ii. **Carbon Sequestration:**

The highly recalcitrant nature of biochar allows it to remain stable in soils for hundreds to thousands of years, serving as a long-term carbon sink. This stability is due to the condensed aromatic structure formed during pyrolysis, which is resistant to microbial decomposition. Applying biochar to soils can effectively sequester atmospheric carbon dioxide, mitigating greenhouse gas emissions.

iii. **Wastewater Treatment:**

Biochar possesses a highly porous structure and large specific surface area, which makes it an effective adsorbent for removing persistent organic pollutants, pharmaceuticals pollutants, and heavy metals from wastewater. Its surface functional groups can interact with various contaminants, facilitating their removal through adsorption and ion exchange processes.

iv. **Air Purification:**

The presence of functional groups, such as carboxyl, hydroxyl and carbonyl, on the surface of biochar enables the adsorption and removal of airborne particulate matter, volatile organic compounds, and other gaseous pollutants. Biochar can be used in air filtration systems or as a coating for building materials to improve indoor air quality.

v. **Energy Production:**

Biochar can be used as a renewable and carbon-neutral fuel source for co-firing in existing coal-fired power plants or gasification systems. Its high calorific value and low moisture content make it an attractive alternative to fossil fuels. Additionally, the pyrolysis process used to produce biochar can generate bio-oil and syngas, which can be used for energy generation.

vi. **Catalyst/Support:**

The unique physicochemical properties of biochar, such as high surface area, porosity, and the presence of functional groups, make it a promising catalyst or support material for various catalytic reactions. These include catalytic pyrolysis, gasification, and other chemical transformations in industries like biofuel production, chemical synthesis and environmental remediation.

vii. **Animal Feed Additive:**

The inclusion of biochar in animal feed can improve feed conversion efficiency by modulating gut microbial populations and enhancing nutrient absorption. It can also reduce enteric methane emissions from ruminants by altering ruminal fermentation pathways. Additionally, biochar may enhance the quality of animal products, such as meat and milk, by binding to toxins and improving animal health.

Advantages of biochar

The advantages of producing biochar from agricultural crop residues, are as follows:

- Waste Management: Biochar provides a sustainable way to valorize agricultural crop residues instead of burning them.
- Soil Amendment: Biochar improves soil fertility, water retention, aeration, crop productivity while reducing chemical fertilizer dependency.
- Carbon Sequestration: Biochar sequesters stable carbon in soil for long periods, mitigating climate change by reducing greenhouse gas emissions.
- Environmental Remediation: Biochar having high sorption capacity which enables removal of organic and inorganic pollutants from soil, water, and air.
- Renewable Energy: Biochar can be used as a renewable and carbon-neutral source of fuel for energy production.
- Economic Benefits: It will create new economic opportunities and revenue streams for farmers and rural communities through biochar-based products and services.
- Greenhouse Gas Reduction: It diverts crop residues from open burning, reducing methane and nitrous oxide emissions.
- Circular Economy: It transforms waste materials into valuable products, promoting sustainable resource utilization and waste minimization.

Conclusion

The production of biochar from agricultural crop residues presents a promising and sustainable solution to address numerous challenges we currently face. By valorizing massive quantities of agricultural waste, estimated at 500 million tons annually in India alone, biochar production offers a novel approach to resource management, moving away from practices that contribute to air pollution and greenhouse gas emissions.

Moreover, biochar serves as a vital tool in mitigating climate change by acting as a long-term carbon sink when applied to soils. Its stability and recalcitrant nature allow it to effectively sequester atmospheric carbon dioxide, aligning with global efforts to combat climate change.

Furthermore, biochar exhibits unique physicochemical properties that enable it to remediate environmental pollutants from soil, water, and air, addressing pollution challenges effectively. Additionally, its use enhances soil fertility, water retention, and microbial activity, promoting sustainable agricultural practices while reducing dependency on chemical fertilizers.

Notably, biochar's high calorific value and low moisture content make it a promising renewable and carbon-neutral fuel source, offering potential alternatives to fossil fuels for energy production. This opens avenues for economic opportunities, with the development of a biochar-based industry creating new revenue streams for farmers and rural communities, thereby contributing to economic empowerment and sustainable development.

Overall, the conversion of agricultural waste into biochar exemplifies the principles of a circular economy, promoting sustainable resource utilization and waste minimization. In conclusion, biochar production and utilization from agricultural crop residues hold immense potential in addressing pressing issues such as waste management, resource depletion, and environmental degradation, while paving the way towards a more sustainable future for generations to come.

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