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Theoretical Investigation of the Torrefaction Process and the Enhanced Properties of the Torrefied Fuel

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Abstract

Biomass has long been used as a source of renewable energy but its use has been surpassed by fossil fuels due to its lower calorific value and long term storage and handling problems. In order to enhance the use of biomass torrefaction process has been developed.
Torrefaction is a pretreatment process in order to increase the efficiency of biomass. Torrefaction is a mild form of pyrolysis carried out between temperature range of 200-3000C in the absence of oxygen. The resulting torrefied biomass is a better hydrophobic fuel with higher calorific value than the original biomass, low SO2 and NOX emissions and much easier storage and handling.
The paper is literature synthesis of the principles of torrefaction, the process technology and compares the properties of the torrefied product with the original biomass. It also pays attention to the scope of the torrefaction process and its utilization in development of green energy.

1. Introduction

Biomass has since long been used as a source of energy. The various advantages of biomass were that it is freely found renewable energy source, carbon neutral, almost nonpolluting. With increase in industrialization the use of fossil fuels started gaining importance. In view of the depleting fossil fuel reserves throughout the world attention now needs to be given to the enhancement of biomass energy. Techniques need to be developed which can increase the energy obtained through biomass. One such technique which can increase the energy obtained through biomass is torrefaction. Torrefaction is a biomass enhancement technique carried out in the temperature range of 200-300 ^{0}C in near atmospheric condition in the absence of oxygen. The torrefied product is a better hydrophobic fuel with high energy density, improved grindability and much easier storage and handling.

The process also helps in environmental preservation as it emits low SOx and NOx emissions and is carbon neutral.

2. Principle/ Mechanism

Torrefaction is a mild form of pyrolysis carried out in the temperature range of 200-300 ^{0}C in the absence of oxygen. It is carried out at atmospheric condition and is accompanied by low heating rate. During the process the biomass decomposes giving off various types of volatiles which results in loss of mass and chemical energy to the gas phase.The yield of mass and energy from the original biomass to the torrefied biomass is strongly dependent on torrefaction temperature, reaction time, and biomass type. Typical values are a mass and energy yield of 0.8 and 0.9 respectively (LHVdar). Hence, in torrefaction more mass than energy is lost to the gas phase. This phenomenon results in energy densification (higher LHVdar), on 'as received' basis' the mass and energy yields can be even 0.45 and 0.9 respectively (35% moisture content) [1].

Biomass (woody and herbaceous) is composed of three main polymeric structures- cellulose, hemicelluloses and lignin. These three together is called lignocelluloses [1, 2].These three operating at different reaction temperature. Hemi -cellulose is most reactive and is subjected to limited devolatilisation and carbonisation below 250°C. Above 250°C it is subjected to extensive devolatilisation and carbonisation. Cellulose is most thermo-stable and is subjected to limited devolatilisation and carbonisation only. Lignin's reactivity is between the two [1].

During the process the water from the biomass is lost and there is loss of moisture content from the substance.

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3. Mechanism

The process of torrefaction can be divided into five distinct stages according to temperature time profile as proposed by Bergman et al. [3]. Stage1 is the initial heating during which the temperature of the biomass increases up to 100^0C and water starts to evaporate. Stage 2 is the predrying phase during which the biomass temperature does not increase and all the free water evaporates. Stage 3 is between post drying and intermediate heating stage and occurs from 100-2000C. During this phase physically bound water is released and some dry matter loss occurs due to loss of organic matter. Stage 4 starts once temperature of biomass increases up to 2000C. During this phase the decomposition reaction of biomass starts. The end of the torrefaction phase is considered to be in the moment when the temperature drops below 200 oC, even though a very limited mass loss occurs when the temperature falls below the maximum torrefaction temperature. The temperature of the torrefaction reaction is defined as the maximum biomass temperature. The stage 4 is responsible for the largest dry matter loss over the course of the whole process. In the stage 5, cooling of the solid, torrefied biomass down to room temperature takes place [2].

4. Feed Stock Requirement

The torrefied biomass can be obtained from a variety of woody and herbaceous biomass substances [4]. A variety of biomass products can be torrefied to yield torrefied biomass. However the mass and energy yield of the torrefied biomass varies from one substance to another depending upon the original biomass and the operating conditions because of polymeric conditions and reactivity of different substances. The particle size also does not affect the torrefaction process. Therefore any size of particle can be used in the torrefaction process.

5. Process

The torrefaction process is carried out in a torrefaction reactor carried out in the required temperature range of 200-3000C. During the process slow heating is provided and near atmospheric conditions are maintained itself in the suitably designed reactors.

6. Products

The result of the torrefaction process is a torrefied biomass which is dark brown in color and volatiles. The torrefied biomass is a hydrophobic fuel which is of higher calorific value and higher density than the original product. Because of the loss of water and other volatiles during the process there is loss of mass in the product. The loss of moisture and slow heating also helps in storing the torrefied biomass for a longer time due to absence of any fungal activities. The torrefied biomass can also be easily transported. The volatiles are comprised of permanent gases and condensable, according to their state and room temperature. The volatiles are formed of permanent gases like CO2, CO, and smaller amount of H2, CH4 and other light C2 hydrocarbons [5, 6]. Carbon dioxide represents the largest fraction of permanent gases. CO2 comprises of the largest fraction of permanent gas. CO is the second most abundantly found gas.

The process also emits gases like SOx and NOx but in lesser amount as compared to fossil fuels like coal [4].

7. Product Properties and Application

Appearance- The torrefied biomass appears dark brown to black in color. Even though the torrefied biomass retains the dimension and shape of the raw material, it has low bulk density.

Grindability- The grindability of the biomass is increased due enhancement of biomass brittleness. Thos property is useful in gasification and pyrolysis especially in fluidized bed systems.

Hydrophobicity- The torrefied biomass is a hydrophobic, water repelling fuel. Torrefaction improves the water repelling characteristicsof biomass through the elimination of hydroxyl groups responsible for hydrogen bondingwith water molecules, and the generation of a non-polar, hydrophobic compound [2, 7, 8].

Energy Density-The energy density of biomass increases as a result of oxygen loss during torrefaction. This increase can be in the range between 102-120%, depending on reaction conditions [9]. Energy and bulk density of torrefied biomass can be further improved via pelletizing [2].

Combustion properties- Torrefied biomass created a greater heat of combustion due to a higher fixed carbon content. In addition, the ignition time of volatiles and char decreased as a consequence of torrefaction, which could be an advantage during combustion.

8. Conclusion and Future Scope

Torrefaction is a biomass up gradation technology for combustion and gasification process. The product of torrefaction, the torrefied biomass is a coal like substance which is of higher calorific value than the original biomass. Also this process helps in environmental preservation since it emits less Sox and NOx emissions as compared to fossil fuels.

The future of torrefaction lies in up gradation of the torrefaction reactors which can increase the calorific value of the end product and also in improve the operating condition. Attention also needs to be given to the economics aspect of the process which can help in its commercialization and aid in development of green energy source.

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