ARTICLE IN PRESS

Renewable and Sustainable Energy Reviews xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

A review on the current status of various hydrothermal technologies on biomass feedstock

Mayank Kumar, Adetoyese Olajire Oyedun, Amit Kumar*

Department of Mechanical Engineering, 10-263 Donadeo Innovation Centre for Engineering, University of Alberta, Edmonton, Alberta T6G 1H9, Canada

ARTICLE INFO

Keywords:
Hydrothermal conversion
Hydrothermal liquefaction
Hydrothermal gasification
Hydrothermal processing
Biomass

ABSTRACT

Hydrothermal processing, a thermochemical approach, is an excellent method of converting energy-rich biomass into useful products. This approach offers the advantage of handling biomass with relatively high moisture content by precluding an energy-intensive pretreatment step. Hydrothermal processing is of world-wide interest in view of depleting fossil-fuel reserves and increased environmental greenhouse gas emissions. There is potential to develop this novel technology at demonstration scale. This paper reviews the three hydrothermal technologies, namely hydrothermal liquefaction, gasification and carbonization, to provide insight into the likelihood of commercialization. The study discusses the role of different process parameters that have key impacts on the quality and yield of the desired products. This study also identifies the gaps in the literature including the need to establish a baseline to develop key process models and to perform a techno-economic assessment to get a better sense of the viability of the technology in future.

1. Introduction

Increasing energy demands related to increasing population, rapid industrialization, and stringent environmental regulations call for alternative routes of energy production, as conventional energy derived from fossil fuels cause severe environmental harm through the release of greenhouse gas emissions. Moreover, the imbalance in supply and demand makes it inevitable that substitutes for conventional energy sources are needed [1]. Biomass refers to biological matter or waste obtained from living organisms that has solar energy stored in it. It is deemed to be a potential energy source [2,3] and is considered to be inexpensive, clean, and environmentally friendly. Biomass wastes include plants or plant-based wastes, municipal wastes, industrial wastes, animal wastes, and household wastes. Due to its renewability and sustainability, biomass waste could become a viable alternative source of energy and, moreover, is expected to provide 25% of the world's energy demand [4]. Biomass with high moisture content is not economical to process by conventional technologies, as a significant amount of energy goes into the drying process. Hydrothermal processing is efficient as it eliminates the costly drying step, thereby making it attractive. The energy required for drying exceeds that used for hydrothermal processing at supercritical conditions for biomass with a moisture content of 30% or greater [5].

Hydrothermal processing is a thermochemical process that involves thermal disintegration of biomass in hot compressed water, wherein a series of complex reactions causes changes in the water's physical properties (i.e., its density, solubility, and dielectric constant) [6]. The process converts biomass into a solid (bio-char), a liquid (bio-oil or bio-crude), or a gas (e.g., hydrogen, methane). The process also leads to byproducts that can be used for power generation and the recovery of useful nutrients [7]. The desired products are obtained by manipulating variables such as temperature, pressure, catalyst, and time [8]. Of late, hydrothermal processing technologies have been the subject of major research for a range of biomass types including agricultural wastes and algae [9,10]. There are many challenges facing the commercialization of these technologies, including expensive and complex reactors [11] that require high capacity water handling equipment [9]. Overall poor understanding of mass balance further make it difficult to accurately measure product yields during the hydrothermal run [12]. The hydrothermal processes (carbonization, liquefaction, and gasification) illustrated in Fig. 1 are based on data from Kruse et al. and Toor et al. [13,14].

Thermochemical processing technologies have been used since 1788 to convert biomass to bio-crude [15]. They are gaining widespread interest as a means of catering to energy demands and tackling growing environmental concerns related to increasing global warming and decreasing fossil fuel reserves.

Hydrothermal processing can produce energy-dense fuels and valuable chemicals. The process allows efficient heat integration and thus takes into account the energy penalty due to water valorization

* Corresponding author.
E-mail address: Amit.Kumar@ualberta.ca (A. Kumar).

http://dx.doi.org/10.1016/j.rser.2017.05.270
Received 8 November 2016; Received in revised form 20 March 2017; Accepted 29 May 2017

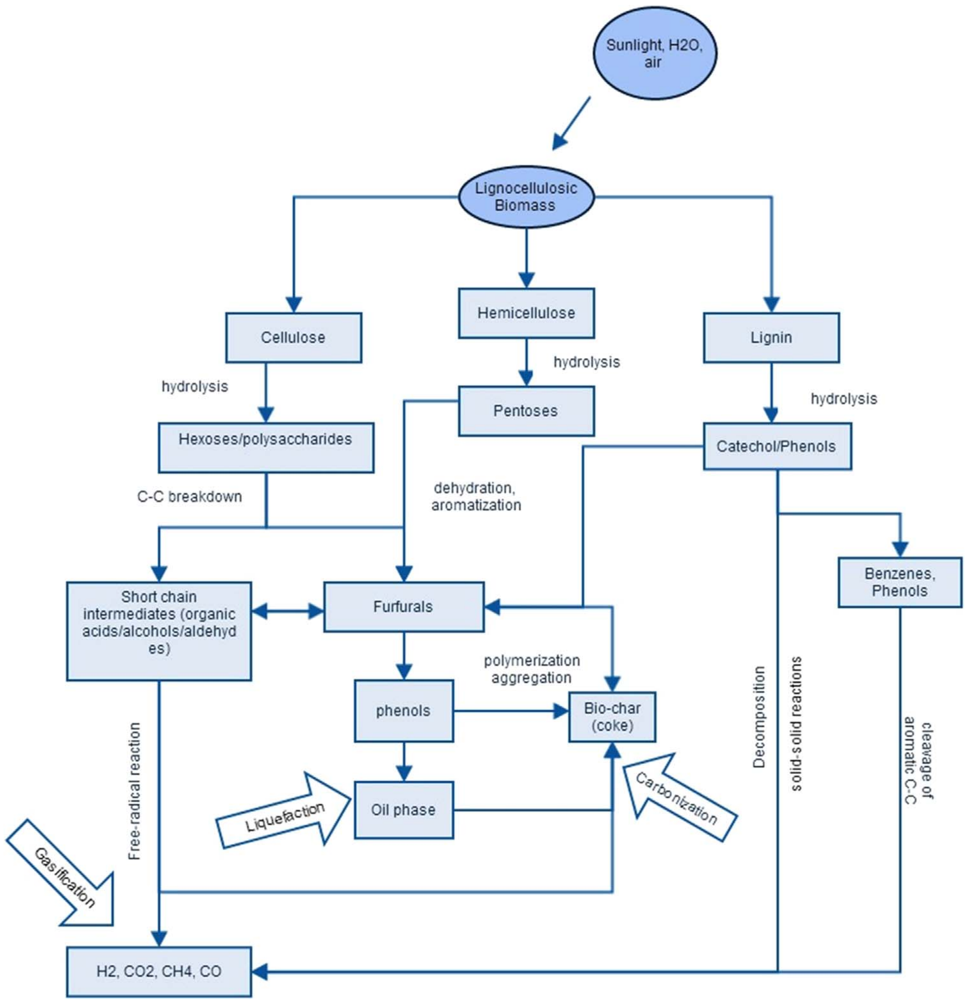

Fig. 1. Schematic of a hydrothermal processing technology.

from hydrothermal media [16]. The hydrothermal processing such as liquefaction and gasification produces an aqueous phase. The residual carbon of the aqueous phase can be used to produce biogas through anaerobic digestion. The gas thus produced can be used for heat and to generate electricity through a combined heat and power generation system and, therefore, the hydrothermal process coupled with anaerobic digestion allows a useful use of energy, thereby reducing energy requirements in the process [17,18]. With that said, the use of organics in the aqueous phase is also a way to reduce the operating costs of the hydrothermal technology, as using organics helps reduce wastewater treatment costs. In the case of algal feedstocks, the aqueous phase has biogenic carbon, phosphorous, nitrogen, and micronutrients that can be recycled for algal cultivation purposes. In addition, high value chemicals such as ethanol, acetone, and acetic acid can be obtained through extraction and catalytic processes [19]. Furthermore, a pinch analysis can be used to optimize the process by identifying intensive heat streams, i.e., heat can be recovered and used in the process to make hydrothermal technology more economical [20,21]. Considerable improvements in homogeneous and heterogeneous catalysts, including metallic catalysts, have led to major advancements in hydrothermal processing technologies [22].

Hydrothermal processing operates in one of two states: subcritical and supercritical. The states are defined with respect to the critical point of water (T_c = 373 °C, p_c = 22.1 MPa). The hydrothermal process commences with the dispersion of the water-soluble part of biomass into water at 100 °C followed by subsequent hydrolysis above 150 °C, causing the disintegration of the cellulosic and hemicellulosic fractions of biomass into its monomeric chains. Then, slurry forms at 200 °C under 1 MPa and proceeds towards either liquefaction or gasification depending on the desired product [8]. The first study on supercritical water gasification was published by Modell [23], who used maple wood sawdust as a feedstock. Research efforts have been underway in this promising field for a long time, and hydrothermal technology research has had a sudden upsurge in publications that show the technology's potential for biomass conversion. However, existing knowledge is disconnected, and this review aims at collecting and analyzing the existing experimental studies on hydrothermal technologies. It is challenging to establish the research findings due to the variations that arise from different types of feedstock and reaction environments. Hydrothermal technology processes, along with process parameters needs, need to be understood. Hence, the overall objective of this paper is to conduct a review of the hydrothermal processing of biomass feedstocks. The specific objectives are:

- To review and summarize hydrothermal liquefaction processes and discuss operating parameters that have a major impact on the processes
- To review and detail the experimental studies on the catalytic hydrothermal liquefaction process of different biomass feedstocks
- To review and analyze the reaction mechanisms of the hydrothermal gasification process and study the operating parameters
- To review and illustrate the experimental studies on the catalytic hydrothermal gasification process of different biomass feedstocks
- To study and provide a brief account of experimental studies on the