



Biomass pyrolysis—A review of modelling, process parameters and catalytic studies



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ABSTRACT

Biomass as a form of energy source may be utilized in two different ways: directly by burning the biomass and indirectly by converting it into solid, liquid or gaseous fuels. Pyrolysis is an indirect conversion method, and can be described in simpler terms as a thermal decomposition of biomass under oxygen-depleted conditions to an array of solid, liquid and gaseous products, namely biochar, bio-oil and fuel gas. However, pyrolysis of biomass is a complex chemical process with several operational and environmental challenges. Consequently, this process has been widely investigated in order to understand the mechanisms and kinetics of pyrolysis at different scales, viz. particle level, multi-phase reacting flow, product distribution and reactor performance, process integration and control. However, there are a number of uncertainties in current biomass pyrolysis models, especially in their ability to optimize process conditions to achieve desired product yields and distribution.

The present contribution provides a critical review of the current status of mathematical modelling studies of biomass pyrolysis with the aim to identify knowledge gaps for further research and opportunities for integration of biomass pyrolysis models of disparate scales. Models for the hydrodynamic behaviour of particles in pyrolysis, and their interaction with the reactive flow and the effect on the performance of the reactors have also been critically analyzed. From this analysis it becomes apparent that feedstock characteristics, evolving physical and chemical properties of biomass particles and residence times of both solid and gas phases in reactors hold the key to the desired performance of the pyrolysis process. Finally, the importance of catalytic effects in pyrolysis has also been critically analyzed, resulting in recommendations for further research in this area especially on selection of catalysts for optimal product yields under varying operating conditions.

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1. Introduction

There is a worldwide drive for reducing reliance on fossil fuels, the burning of which contributes significant amount of carbon emissions leading to global warming [1]. Also, there is a shift from non-renewable energy sources to bio-energy due to continuous depletion of fossil fuels. Furthermore, since biofuels are derived from biomass, they significantly decrease emissions of harmful gases such as SO_x and NO_x [2]. Examples of commonly used biomass include plant matter such as forest residues (dead trees, branches and tree stumps), yard clippings, wood chips and municipal solid waste. The benefit of using biomass arises due to its renewable nature which comes from the ability to utilize the emitted CO_2 for growing next generation of biomass through photosynthesis cycle. Consequently, in recent years, the use of biomass-derived fuels has been steadily increasing, and they currently contribute around 13% of the world's energy supply [3].

Biomass may be converted to biofuels using a number of physical, thermo-chemical and bio-chemical processes as shown in Fig. 1. The physical processes use densification techniques including crushing, heat and pressure applications for biomass conversion into biofuels. The bio-chemical processes use enzymes and micro-organisms to convert biomass into desirable energy products. On the other hand, the thermo-chemical processes use

heat energy and chemical catalysts for decomposition of biomass into high value energy products.

In the direct combustion of biomass, the primary product is the thermal energy, which may be used as the energy source for the production of electricity, or for the combined heat and power (CHP) production plants. The biomass gasification process is used for production of bio-fuels such as “green” gasoline and also electricity. Pyrolysis process is used for production of bio-fuels, chemicals and charcoal with electricity and CHP generation using turbines, engines and boilers. The hydrothermal liquefaction process may be used for direct conversion of biomass into crude oil for generation of heat and power or, after upgrading using hydrotreating or hydroprocessing, as premium liquid transport fuels.

As shown in Fig. 1, pyrolysis is a thermo-chemical decomposition process in which organic material such as biomass is converted into a carbon-rich solid and a volatile matter by heating in the absence of oxygen [4]. The solid product of this process is known as the biochar or char, and is generally high in carbon content. The volatile fraction of this process is partly condensed to a liquid fraction called tar or bio-oil along with a mixture of the non-condensable gases. The bio-oil is stored and further used for energy production. The gases can be utilized for providing heat energy to the pyrolysis reactor. The pyrolysis products are formed from both primary decomposition of the solid biomass as well as

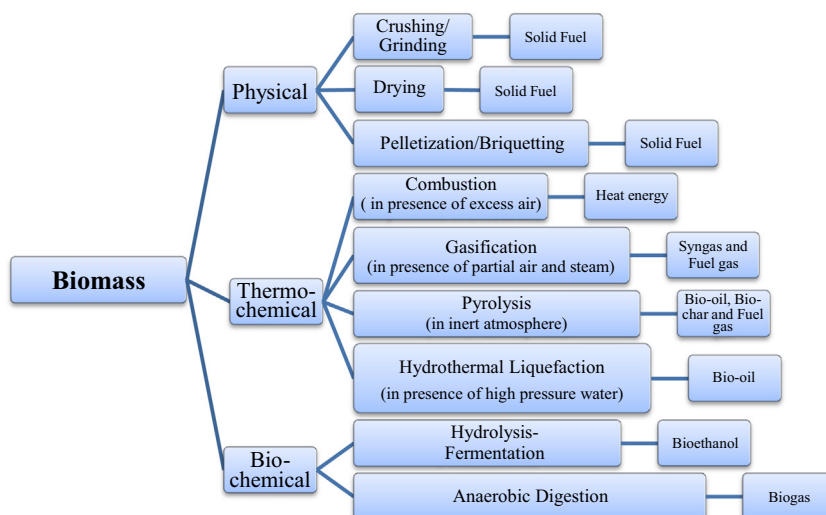


Fig. 1. Biomass to bioenergy conversion pathways.

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