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Pretreatment of lignocellulosic wastes for biofuel production: A critical review

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ABSTRACT

Protection of environment is of immediate concern and this can only be achieved by avoiding the use of chemicals for fuel production. Lignocellulosic waste is becoming popular as a feedstock for biofuel production. The can be converted into usable form for biofuel production by using a suitable pretreatment method. Different pretreatment methods have been used by researchers which are physical, chemical, physico-chemical, biological and combined pretreatments. Evidently chemical pretreatment is found to be more expensive as a large amount of chemicals are used for pretreating the lignocellulosic substrate. It has been shown that combined pretreatments are more effective as compared to single pretreatment and there is an extensive scope of combinations which can also be applied in future. Recent review critically discusses and compares different pretreatment methods, biomass resources, chemical composition of different agricultural biomass and the use of this biomass for bioenergy generation. Various pretreatment processes used for bio-hydrogen, bio-methane, bio-ethanol, bio-methanol bio-butanol and bio-diesel production are also discussed.

1. Introduction

Economic development around the globe have recently demanded the need for alternative resources of energy mainly, due to the harmful effects of using fossil fuels (coal, oil, natural gas etc.), such as greenhouse effect, global warming etc. Excessive consumption of fossil fuels, most common in urban areas, has increased pollution during the last few decades. This has also resulted in the high emission levels of greenhouse gases (GHGs) in the Earth's atmosphere [1], global warming and an increase in price and unexpected environmental fluctuations [2]. All these weakness of fossil fuels along with its fast depletion have strengthened the idea of alternative, renewable, sustainable and cheap energy sources such as biofuels i.e. bio-hydrogen, bio-methane, bioethanol, bio-methanol, bio-butanol etc.

Robust increase in human population is accompanied with the generation of large amounts of different types of wastes and an urgent need to solve the problem of waste disposal has emerged. Investment of energy for waste disposal is not economical but utilisation of waste for energy production is promising. There is renewed interest in the production and use of plant origin fuels or organic (biodegradable) wastes for sustainable energy development. It also helps in development of economy and society in an eco-friendly manner. Biomass resources are the only renewable and suitable primary energy resource that can provide various alternative transportation fuels in the short-term [3].

1.1. Where do we stand at present time?

We are living in the age of technology and development in technology also leads to the development of various resources and methods used for pretreatment and production of biofuels from lignocellulosic biomass. Pretreatment technologies have developed simultaneously with the development of methods used for biofuel production [3]. A number of modifications were also applied in engines of automobiles, to utilise biofuels like bioethanol and biodiesel as they could blend with petrol and improves its efficiency. Biohydrogen can also be used for running vehicles, but there are many problems related to storage and transportation of biohydrogen. Various pretreatment methods have

Abbreviations: MW, Microwave; Ext, Extrusions; Frz, Freezing; Acd, Acid pretreatment; Oxd, Oxidative pretreatment; Alk, Alkaline pretreatment; IL, Ionic liquid pretreatment; Orgv, Organosolv pretreatment; AFExp, Ammonia fibre explosion; US, Ultrasonication; SExp, Steam explosion; LHW, Liquid hot water pretreatment; WO, Wet oxidation; CO_2 Exp, CO_2 Explosion; FP, Fungal pretreatment; MCons, Microbial consortium pretreatment; Enz, Enzymatic pretreatment; SO_2-SExp, SO_2 and steam explosion; EH-SFG-SExp, Enzyme hydrolysis and superfine grinding with steam explosion; DA-SExp, Dilute acid and steam explosion; $SCCO_2$-SExp, Supercritical CO_2 and steam explosion pretreatment; Bio-DA, Biological and dilute acid pretreatment; Bio-Orgv, Biological and organosolv pretreatment; DA-MW, Dilute acid and microwave pretreatment; Bio-SExp, Biological and steam explosion; MW-ACD, Microwave assisted acid pretreatment

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been used for the pretreatment of different kinds of biomass but most of chemical pretreatment methods utilised excessive amount of expensive chemicals. Physical pretreatment require high amount of energy which affects its feasibility and cost effectiveness. Many new technologies developed today are still limited to the lab scale production of biofuel and there is a need to develop such techniques which are feasible, cost effective and can be commercialised easily.

The motivation of this review was achieved from the literature surveyed for the preparation of Ph.D. synopsis and it was found that a number of pretreatment methods have been used by several researchers and most of them resulted in contamination of environment due to large amount of chemicals used in the pretreatment process. This review critically describes various lignocellulosic biomasses used in recent years, composition of biomass, production of biofuels from different biomasses, comparison of various pretreatment processes used for biomass pretreatment and their effects on biofuel yields.

2. Biofuels and importance of biofuels

Biofuels are defined here as organic fuels derived from agricultural biomass through contemporary biological processes and can be used for the generation of thermal energy by combustion or by use of other technology [4]. According to Anselm Eisentraut, International Energy Agency (IEA) [5] biofuels currently provide approximately 1.5% of global transport fuel, as a result of rapidly increasing production over the last decade. Recently, to reduce GHGs and for waste disposal, biofuel production has been preferred since biofuels are light, less carbon containing, high energy producing, cheap and low pollution causing agents.

2.1. Biomass to biofuels

In 2012, the estimated global petroleum consumption was about 89 million barrels per day from which about a half was used for gasoline production. The fossil fuel resources at this rate of consumption are predicted to run out within the next 50 years [6]. Biofuels offer a key solution for the present challenge since it is produced through renewable biomass resources. Biofuels can be classified into three main categories: First generation, second generation and third generation biofuels (Fig. 1), while the fourth generation biofuels [7] make use of novel synthetic biology tools and are just emerging at the basic research level. The “First generation” biofuels are generally produced from agricultural crops (sugarcane, sugar beet, wheat, rice, soybean oil, sunflower and palm oil etc.) and there is a highly mature technology in converting crops to biofuels [8]. The consideration of using crops for food or for biofuel may be referred to as “Food v/s Energy” conflict. Therefore, researchers opted for the production of second and third generation biofuels which can be obtained from non-food crops, grasses, agricultural and food wastes, algae etc. The “second generation” biofuel production mainly focuses on the production of biofuels from the renewable resources, which could help to minimize the fossil fuel combustion and CO_2 emission in concern to prevent our “Earth” from global warming. Thus, the utilisation of biomass resources is one of the most effective factors to protect our environment in the 21st century [9]. Examples of wastes which can be used for second generation biofuel production are municipal solid wastes, used cooking oil, industrial wastes, agricultural wastes, and sewage sludge. Biofuels such as biodiesel, bioethanol, bio-methanol, bio-butanol, biogas, and biohydrogen can be produced from them [8]. The “third generation” biofuels are mainly derived from algae feedstock. Bioethanol can be produced from algae feedstock and is known as one of the most important renewable energy source [10]. The “fourth generation” biofuels which are mainly photo biological solar fuels & electro-fuels and are expected to bring fundamental breakthroughs in the field of biofuels. Production of these solar biofuels is an emerging field technology and is based on the direct conversion of solar energy into fuel by use of raw materials which are inexhaustible, cheap and widely available [7]. First, second and third generation biofuels are derived from biomass whereas fourth generation biofuels take advantage of synthetic biology of algae and cyanobacteria [11–13].

Recently production of second and third generation biofuels is advantageous over first and generation biofuels as they are derived from agricultural residues and algal biomass respectively. Algal biomass is more abundant in nature, mainly grown in various types of wastewater sources [10].

2.2. Biomass resources and biomass from agriculture

A wide variety of biomass can be used for biofuel production. The annual global primary production of biomass is about 220 billion tonnes on dry weight basis that is equivalent to 4500 EJ of solar energy captured each year. From this biomass, an annual bioenergy market of 270 EJ is possible on a sustainable basis [14]. Other biomass resources are wood and wood wastes, agricultural crops and their waste by-products, MSW, animal wastes, wastes from food processing, aquatic plants and algae. Maximum biomass energy is produced from wood and wood wastes (64%), followed by MSW (24%), agricultural waste (5%) and landfill gases (5%) [15]. Fast growing species such as poplar, willow or

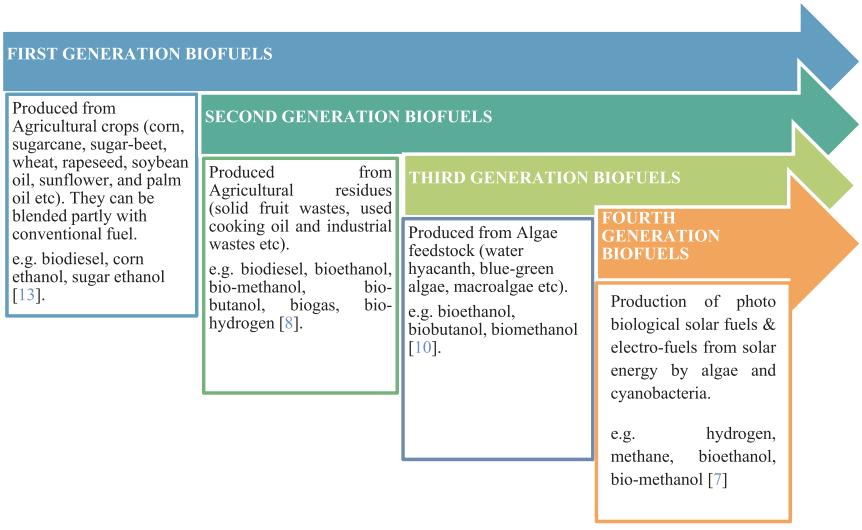

Fig. 1. Classification of biofuels.