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Global challenges in the sustainable development of biomass gasification: An overview

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ABSTRACT

Biomass has proven to be an effective energy carrier capable of fulfilling the growing demand of clean and everlasting energy source for the sustainable development of society. Among different biomass conversion routes, biomass gasification is one of the most promising thermochemical routes for conversion of biomass into gaseous fuel for both heat and power generation applications besides biofuel production through fermentation. But, we are unable to present these gaseous fuels directly for domestic and commercial uses, which indicates the existence of various barriers including the lack of research in this area. In this article, various barriers to the technology, such as challenges with biomass supply chain management, biomass pretreatment, generic shortcomings, gas conditioning and conversion technology have been highlighted. Based on recent studies, the gasification of biomass, gas conditioning, government policies and utilization of fuel gas for heat and power generation applications have been identified as the greatest challenges. Despite the availability of different gasifier reactors, a highly efficient reactor design is yet to be developed for successful operation and commercialization. Thus, an advanced gasification system with efficient gas conditioning technology can significantly overcome many of the barriers.

1. Introduction

Due to uncertain price rises in fossil fuels and their contributions climate change, the global demand for clean energy has been steady increasing over the past decades to meet the rapid pace of industrialization. Thus, the world community is diverting its attention towards the wide exploitation of clean energy resources such as, solar, biomass, wind, etc. for the sustainable development of society. Biomass is one of the promising forms of clean and green fuel that can meet day to day energy requirements. Its use predates the use of fossil fuels such as, petroleum, natural gas and coal [1]. Biomass makes a significant contribution (about 14%) to global renewable energy utilization, while in rural areas of developing countries this contribution is up to 90%. Since around 90% the world population is expected to reside in developing countries by 2050, biomass is likely to remain a major source of energy for those large populations [2–4]. India offers a conducive environment for the development and industrialization of bioenergy at various scales. In the Indian scenario of bioenergy, around 25% of primary energy comes from biomass resources and approximately 70% of rural populations utilizes biomass as the primary energy source to fulfill their daily energy requirements. Therefore, India has great potential for the adoption of renewable energy in general and bioenergy in particular. The market for bioenergy in India is growing exponentially which is fulfilling the energy demands of about 90% of rural and 40% of urban populations [5,6]. The exploitation of biomass as an energy resource can provide dual benefits in the sense of reduction of carbon dioxide emissions and fuel security as it is abundant. Further, biomass is capable of providing employment and additional income for farmers.

Despite the various advantages of bioenergy as a clean energy source, it is not being utilized at commercial levels due to the existence of various challenges associated with the biomass supply chain management and conversion technologies, as well as generic shortcomings. Thus, bioenergy has not been considered appropriately in most energy studies and is, therefore, classified as ‘non-commercial’ energy. At the time of harvesting, biomass especially agricultural residues may have excessive moisture (> 50%) and cannot be stored as such before proper drying. Besides, the transportation cost associated with moist biomass has been reported to be very high [7,8]. Further, the origin of biomass particularly the agricultural biomass is

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mainly in rural areas and can only be managed properly with extensive involvement of local communities. So, local bodies should be motivated and facilitated with all necessary sources, such as advanced machinery, policies, marketing, etc. for the mass production and utilization of excess biomass in the area [9]. Therefore, biomass supply chain management plays an important role in the continuous supply of biomass to biomass conversion units.

In addition to biomass handling, pretreatment like drying, densification, grinding etc. is equally important for improving the effectiveness of biomass processes. The solar drying of biomass is cheap but ineffective under low solar irradiance and thus takes a long time for product drying. Conventional drying methods are cost and energy intensive but their drying rate is high [10]. Besides, the complete drying of biomass has not been reported to be beneficial particularly in gasification because the addition of water in biomass becomes necessary to balance the hydrogen yield in the producer gas. Therefore, biomass should have a requisite or limited amount of moisture (≤ 40%) for cost and gas quality benefits [11]. The briquetting of biomass has been observed to be an attractive method for commercial utilization of biomass as compared to balling and pelletizing in terms of heat transfer characteristics, transportation, storage and feeding to conversion units [12]. Generic shortcomings associated with progress in bioenergy have been observed to be fundamental challenges, including a lack of infrastructure, information gaps among people financial burdens and policies drawbacks [5].

The partial oxidation of biomass with limited air at high-temperature conditions is termed as gasification and is one of the prominent key conversion routes of biomass to a combustible gaseous mixture. The quality of fuel gas obtained through gasification depends upon several factors, such as gasifier design (fixed and fluidized bed gasifier), gasifying medium, temperature, pressure, air/fuel ratio and residence time [13]. Both the gas turbine and gas engine require high quality of fuel gas for power generation applications. Fixed bed gasifiers, which can be categorized as updraft or downdraft, are simple in construction and operate at small scale with high carbon conversion rates, low gas velocity and long residence time. These gasifiers have been reported to be affected by tar which also affects the composition of producer gas; however recent progress in tar controlling techniques has provided credible options [14]. On the other hand, fluidized bed gasifiers, which may be bubbling or circulating fluidized bed (CFB) types, are advantageous over fixed bed gasifiers in terms of uniform and fast heat transfer characteristics among the particles in the reactor. However, these gasifiers require small biomass particle size and, hence, contribute to high energy consumption and cost intensiveness [15]. Moreover, impurities such as tar, particulate matter, SO_x, NO_x and NH_3 are likely to be found in the producer gas. The IC engine only operate in the limited presence of such impurities for power generation [16].

Thus, the intensive cleaning of gas mixture becomes important to obtain a fuel gas free from contaminants. Among various contaminants, tar has been identified as the critical one, particularly in downstream applications where it can block gas flow lines [17]. Gas cleaning has been categorized in three processes, namely physical filtration, thermal decomposition and catalytic cracking. Physical filtration has been seen to suffer from pressure drops due to blockages of filter pores, and handling of toxic chemicals such as aromatic hydrocarbons which result in many health and environmental hazards [18]. Thermal decomposition is responsible for high slag formation due to melting of ash at high-temperature conditions [19]. But, the catalytic cracking of tar particle has been observed to be suitable and to have several advantages like the removal of almost all tar particles, conversion of tar into product gas and trapping of other contaminants in the catalyst bed [20,21]. However, this method is expensive and is ineffective if the absorption of carbon or other poisonous gas on the catalyst surface becomes significant and leads to deactivation of the catalyst.

The fuel gas obtained from biomass gasification can be utilized for power generation in several ways, including indirectly through steam and gas turbines or as a direct feed in IC engines. In a steam turbine, the producer gas is fed to the boiler to generate high-pressure steam which passes through a steam turbine connected to an alternator for electricity generation [22]. Despite the low efficiency (10–20%), this process is cost intensive. But it has been reported to be affected by limitations of boiler and steam turbine. The internal combustion gas turbine is another option for fuel gas utilization with good efficiency at small scale. However, these systems also suffer from several technical difficulties. For instance, mixing of fuel gas with impurities may affect gas expansion, and corrosion due to impurities reduces the life cycle of turbine blades. Adequate cleaning of the gas and its utilization in an externally fired gas turbine may overcome the problems associated with the internal combustion gas turbine [23,24]. Lastly, the internal combustion gas engine has also been reported to be a viable option for power generation from biomass and has already been optimized for various compositions of fuel gas and related engine efficiencies [25]. However, these systems are acceptable only with the fulfillment of such requirements as adequate purity of fuel gas and optimized compression ratio. Further, the quality of fuel gas can be improved to desirable levels through catalytic cracking which is, however, expensive but can be viable if the use of a catalyst is properly optimized.

The distribution of power generated from biomass is a complex and cost intensive process if the location of the biomass conversion unit is not accessible to the major electricity network. In such instances, the additional cost associated with the construction of transmission facilities often determines the economic viability of a biomass-based power generation unit [26]. The objective of this article is to review critically the challenges and advances associated with biomass gasification and its role in the sustainable development of bioenergy, and is expected to prove useful to students, apprentices, technology players, stakeholders, researchers and government authorities. In this study, various barriers related to the biomass supply chain management, biomass pretreatment, generic shortcomings, gas conditioning and conversion unit are critically reviewed and presented along with the recommendations based on the literature review.

2. Biomass supply chain management

Biomass is available in various forms, such as forest wastes, agro-residue, municipal wastes and wood, at various scales globally. For example, agro-residues are likely to be found abundantly in rural areas whereas forest-based agricultural and farming wastes are found in forest areas. Thus, the characteristics of biomass, such as moisture content, calorific value, density, etc., are likely to vary geographically [27]. Therefore, biomass characterization is important for selecting the most sustainable and viable conversion route of biomass to bioenergy. For example, moist biomass may have a low heating value, transportation problems and an irregular in shape and size, and, hence, may be difficult to use as feedstock in one conversion unit. However, such biomass may be utilized through another conversion route, such as biogas from dung and vegetable wastes [28]. Therefore, biomass supply chain management is a key factor and plays a pivotal role in the establishment of any biomass conversion unit. It comprises several subprocesses including biomass harvesting, collection, pretreatment, transportation, storage, etc. [29–31]. These are discussed in detail in the following subsections.

2.1. Harvesting

The harvesting of biomass is a labor and cost intensive process which requires machinery and transportation fuels for smooth operation [32]. Thus, the cost of harvesting directly depends on many factors, such as the type of biomass to be harvested, the economic status of the country, the biomass yield in the particular region and the availability of harvesting infrastructure [33]. For example, energy crops