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System analysis for synthesis gas (syngas) production in Pakistan from municipal solid waste gasification using a circulating fluidized bed gasifier

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A B S T R A C T

A synthetic natural gas (syngas) production study via municipal solid waste (MSW) gasification system in a circulating fluidized bed gasifier is presented with the aim to produce clean energy. The syngas production offers a substantial energy alternative especially in regions such as Pakistan where the rates of MSW production are high and resources are less. MSW gasification could be an effective process that will not only contribute to solve solid waste problem but also reduces waste disposal landfills. The capacity of the plant was set based on the availability of feed and selexol process which was integrated with a carbon capture process. The energy conversion performance for the overall integrated process was evaluated based on material and energy balances and the system performance. The plant produced 30 MW of energy from a 50 MW estimated plant capacity. About 84% of syngas is produced from the overall process after capturing the carbon dioxide (CO_2) using Selexol process. A process model was developed using ASPEN PLUS simulator to calculate the performance of the circulating fluidized bed (CFB) gasifier. Effect of gasification temperature, equivalence ratio, and moisture content was analyzed. Higher moisture content results in degradation of syngas quality. Large amount of MSW needs greater heat input and this increases the process cost. Gasifier temperatures were found to have a stronger impact on the syngas composition. The simulation results and energy balances in combination impart useful information in a search of proficient and clean utilization of MSW energy.

Contents

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1. Introduction

Hasty urbanization and industrialization made the characteristics of solid waste vague. As a consequence, the municipal solid waste (MSW) management system required substantial improvement in their technologies. Global MSW estimated generation in 2015 is about 1.3 billion tons per year with an estimated annual growth rate of 4 to 5.6% in developed nations and 2 to 3% in developing nations [1]. It is expected by year 2025; the generation of MSW will be amounting to 2.6 billion tons per year [1]. A significant increase of the waste generation rates per capita has been projected, from the current 1.2 kg/capita per day to 1.42 kg/person per day until 2025. Fossil fuel expenditure is expected to inflate by 42% from year 2015 to 2025 due to extensive usage of fuel products which also raise serious environmental issues such as greenhouse gas (GHG) emissions [2]. Population growth, urbanization and economic development are expected to produce increasing quantities of waste that are overburdening existing waste-management systems [3]. Recently, a review has shown that the domestically available sources of coal, biomass, and natural gas can be used as potential feedstocks in energy and transportation sector [3,4]. In future, biomass-based fuels will have an upper hand due to GHG diminution in policies as well as the depletion of fossil fuels. Biomass is an important feedstock as it is a non-fossil fuel source that can help in mitigation of CO_2 emissions [4]. On the plant level, biomass based processes do have emissions but the capability of absorbing atmospheric CO_2 during photosynthesis may lead to have net negative emissions for the energy production from a life-cycle viewpoint [3–5]. Thus, global focus has been driven towards renewable energy resources especially from biomass feedstocks to attain sufficient energy and utilization of waste materials. Synthetic natural gas (syngas) production is among the important research and development area in the present stage due to the increase in demand for liquid and gaseous fuels [4]. Syngas production may lead to eliminate the pollutants to some extent and decouple the link between energy utilization and greenhouse gas emissions in end – use systems. Syngas production can contribute to more efficient electrical power generation through various advanced energy systems [4–6].

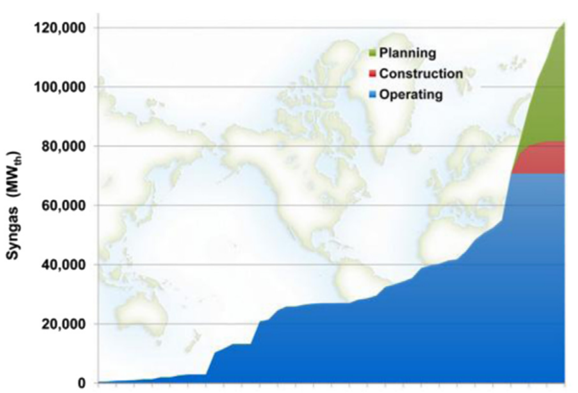

Fig. 1. Worldwide gasification capacity and growth [14].

Considering the issues rose, a large-scale plant for syngas production will require a considerable amount of biomass especially MSW. This leads to the proficient use of MSW in terms of energy source. MSW is a complex heterogeneous resource containing a significant fraction of paper, food waste, wood, cotton, and leather. Materials resulting from fossil fuels such as plastics, rubber, and fabrics are also considered to be a part of MSW. Moreover, separation of MSW into waste categories can augment the homogeneity of the waste streams. It also allocates an optimization of waste reuse, recycle, treatment and yields the utmost benefit owing to the plausible treatment alternatives for each category [7–9]. Waste-to-Energy reduces the amount of materials sent to landfills which in return increases the recycling rates and lessens the dependency on fossil fuels for power generation [10]. Thus, MSW could be a huge source of energy production as every person on the planet is generating a considerable amount of waste depending on the living standards. Recently, the gasification process has turned into a potential practicable technology for energy recovery from waste [11–13]. Gasification is a thermo-chemical conversion of organic feed-stocks mainly into combustible syngas along with other constituents. It has been extensively used to convert coal into gaseous energy carriers but only has been recently observed as a process for producing energy from biomass [14]. In 2010, worldwide gasification technology capacity was about 122,106 thermal MW [15]. Both biomass and waste gasification constitute only 0.33% of the total worldwide gasification capacity as it has a small fraction of total thermal energy produced compared to other main sources (approximately 99.67%) such as pet coke, gas, petroleum and coal [15]. The primary benefit of gasification is the ability to convert biomass into an energy carrier. Fig. 1 shows the worldwide gasification capacity and growth [15]. Coal industry is the largest applicant of gasification technology. Gasification process produces syngas mainly consists of carbon monoxide and hydrogen with small portions of carbon dioxide (CO_2) and methane (CH_4). Gasification has several advantages over other processes as it is generally carried out at low temperatures and produces fewer volatile pollutants [16]. MSW can be gasified to produce syngas mainly CH_4 as a raw component for various biofuel production.

In order to design the overall process with minimal cost, it is crucial to develop a practical model to systematically predict the gasification characteristics. Aspen Plus is a well-known design tool for modeling gasification system. Many investigators have been using Aspen Plus to simulate coal and biomass power generation systems [10,17]. However, only limited studies have been reported on MSW gasification.

The main aim of this work is to check the thermodynamic performance of MSW gasification system under various operating conditions in order to evaluate the exergetic efficiency of the MSW to syngas conversion process for each individual unit using a computer simulation model. Hydrothermal gasification system is applied to obtain CH_4 using supercritical oxidation process. The influence of the gasification temperature and equivalence ratio (ER) on the syngas composition is investigated. In general, overall performance of the system in terms of material and energy balances is computed by estimating steam production, and consumption, as well as electricity for the overall process of plant. This