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A Review on Biomass Gasification in Processing Industries

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Abstract—*Energy is one of the most important aspects of technology and economic development. The energy requirements in the industrial sector have been increasing continuously. There is a vital need to focus on renewable energy source to meet the rising demand and conserve the finite natural resources. Biomass plays an important role in the domestic and industrial sectors. The substitution of conventional fuels with biomass for energy production results in the replacement of non-renewable energy sources. Gasification of biomass appears to be an interesting option to address this energy crisis. This paper gives a review of the various works and researches done on the implementation of biomass gasification in various processing industries in the past few years.*

Keywords*: Biomass, gasification, process industries, energy*

1. INTRODUCTION

Biomass is the oldest form of energy used by human beings. It has either been burned directly in furnaces, or processed to increase its energy content. Biomass is useful to meet different kinds of energy needs, such as fuelling vehicles, providing process heat for industrial facilities, generation of electricity and heating facilities in homes.

Gasification is a thermo-chemical partial oxidation process in which carbonaceous substances are converted into gas in the presence of a gasifying agent. The gas generated is commonly called syngas (synthesis gas). It consists mainly of H_2, CO, CO_2, N_2, and small particles of char, tars, ashes and oils. The energy obtained from biomass is very much feasible to be used in domestic and commercial applications. Various biomass materials can be found in the form of residues of primary use of other applications.

There are many ways by which the energy, available in abundance around us, can be stored and amplified for our use. Energy sources will play an important role in the world's future. Evidently, the cost of producing energy from biomass fuels is less than that from fossil fuels.

2. USE OF BIOMASS IN PROCESS INDUSTRIES

2.1 Biomass in Biorefineries

The use of biomasses is becoming increasingly appealing alternative, to give a partial solution to the lack of energy, with an ecofriendly approach. The biorefinery is the true valuable option of a wide diversification, with by-products like the single cell protein and biogas from the distillery vinasse, new oxidants like methanol, second generation bio-fuels, bio-butanol, etc. In this context Reno, M.L.G., et al., [2] present a study of five different configurations of bio-refineries. Each case study is a system based on an autonomous distillery or sugar mill with an annexed distillery and coproduction of methanol from bagasse. The paper includes the use of sugarcane harvest residues (mainly straw) and a Biomass Integrated Gasification–Gas Turbine plant as alternatives to fulfil the energy requirements.

Consonni, S., et al., [1] present a work from a 2-year study of integrated pulp-mill bio-refineries based on black liquor and wood residue gasification at a large craft mill representative of those in the Southeast United States. It includes detailed mass-energy balance simulations, financial analyses, and energy and environmental benefits estimates for seven pulp-mill bio-refinery process configurations. All seven configurations include an oxygen-blown, high-temperature black liquor gasifier, syngas cooling, clean-up by a Rectisol (methanol) system, and a catalytic gas-to-liquid process. Six of them also include a fluidized-bed, oxygen-blown biomass gasifier and a gas turbine combined cycle fully integrated with the gasification and syngas cooling section. Three biofuels are examined: dimethyl ether (DME), Fischer-Tropsch liquids, and ethanol-rich mixed-alcohols. For the integrated bio-refineries analyzed here, the ratio of useful energy outputs (steam, electricity and fuels) to total energy inputs (black liquor, wood residuals and fuel oil) ranges from 66 to 74%. These values compare with about 57% for conventional systems based on Tomlinson boilers and 65% for gasification combined cycles that produce only electricity. Because of the integration of the bio-refinery with the pulp and paper mill, the adjusted liquid fuel yield per unit of biomass is far higher than for "stand-alone" gasification-based bio-refineries or for ethanol production via biochemical conversion. Besides better energy performance, the integration between the bio-refinery and the pulp mill effectively limits the specific capital investment associated with liquid fuels production to a modest \$60,000–150,000 per barrel of diesel equivalent per day.

Gasification-based pulp mill bio-refinery technologies, once fully commercialized, offer the potential for attractive investment returns and, if implemented widely, significant energy and environmental benefits to the United States.

2.2 Biomass in Olive Industry in Spain

Spain is the first olive oil maker in the world. Currently, there are around 2000 operative olive oil mills in Spain. During the olive oil extraction process, crushed olive pits and rests of small branches and leaves are produced. This biomass source is supposedly a feasible option in gasification technology applied to distribute generation. Yearly, the olive oil industry generates large amounts of by-products like olive pomace, tree pruning, pits, leaves and branches. Vera, D., et al., [4] presents the experimental and feasibility study of a pilot plant for the conversion of olive tree pruning and olive pits into electrical and thermal power. The pilot plant is composed of a downdraft gasifier, gas cooling-cleaning stage and spark ignition engine with a modified carburretor. The experimental results showed satisfactory cold gas efficiency in the range of 70.7-75.5% and good lower calorific value of the producer gas for both raw materials of 4.8 and 5.4 MJ/kg. Moreover, the plant achieved acceptable values for the electric and CHP efficiency of around 15% and 50%, respectively. Finally, the investment achieved reasonable profitability index with a payback period of 5-6 years. As a result, the energy recovery potential from the olive industry wastes may represent a good opportunity to promote distributed generation systems.

Another work of Vera, D., et al., [6] focuses on the modelling of a small-scale plant based on a downdraft gasifier and a gas engine connected to the grid. The producer gas from the gasification process reaches a calorific value of 5.1 MJ/kg (for crushed olive pits) and 3.7 MJ/kg (for small branches and leaves). The system provides 70 kW_e and 110 kW_{th} with a biomass consumption of 105 kg/h. Cycle-Tempo and Matlab/Simulink have been used for simulating and calculating the optimum operating parameters of the plant. Electric efficiency of 14%, overall efficiency of 36% and high gasification efficiencies are likely to be achievable with such a system.

The olive oil industry generates several solid wastes. Among these residues are olive tree leaves, prunings, and dried olive pomace from the extraction process. These renewable energy sources can be used for heat and power production. The aim of this work by the same author [12] consists of modelling and simulation of a small-scale combined heat and power (CHP) plant (fuelled with olive industry wastes) by incorporating a downdraft gasifier, gas cleaning and cooling subsystem, and a micro-turbine as the power generation unit. The gasifier is modelled with thermodynamic equilibrium calculations (fixed bed type, stratified and with an open top). The gasifier operates at atmospheric pressure with a reaction temperature about 800°C. Simulation results (biomass consumption, gasification efficiency, rated gas flow, calorific value, gas composition, etc.) are compared with a real gasification technology. The product gas obtained has a low heating value (4.8-5.0 MJ/Nm^3) and the CHP system provides 30 kW_e and 60 kW_{th}. High system overall CHP efficiencies around 50% are achievable with such a system. The proposed system has been modelled using Cycle-Tempo software.

2.3 Use of Biomass in Other Process Industries

Dry biomass provides considerable benefits for combustion, such as increased boiler efficiency, lower flue gas emissions and improved boiler operations, compared to those with high moisture. Drying is an energy-intensive pre-treatment. Utilising low-grade waste heat, of which large amounts are available from many process industries could significantly reduce energy consumption. Li, H., et al., [5] investigate the integration of a drying process into a power station fuel system. Waste heat from a process industry plant (100 MW_{Output}) is used as the heat source for drying. The biomass, i.e., pine chips at 60 wt% moisture, is dried and then provided as the input fuel for a 40 MW power plant. The process consists of a belt conveyor as the dryer and either flue gases or superheated steam as the heat source. Flue gas usage would result in lower capital costs, but environmental issues, such as pollutant emissions must be considered. Superheated steam can combine short drying times, well heat recovery and environmental protection, but would entail greater capital costs. A 3-4 year return on the initial investment was calculated for both technologies, but profitability was sensitive to fuel price.

Deshmukh, R., et al, [3] compare different cogeneration system scenarios for efficient energy production from bagasse fuel in an Indonesian sugar and ethanol factory. These include the use of condensing-extraction steam turbines, variable speed electric drives for process equipment, measures to reduce low pressure steam demand for process needs, and two advanced cogeneration systems. One advanced system includes an 80 bar high pressure direct combustion steam Rankine cycle (advanced SRC), while the other uses a biomass integrated gasifier combined cycle (BIGCC). Both utilize fuel dryers. By using steady-state thermodynamic models, the net electricity generation potentials of the BIGCC are estimated. The maximum net electricity generation potentials for the respective systems are 170 kWh/tc (BIGCC) and 140 kWh/tc (advanced SRC). However, the BIGCC system needs a bagasse feed rate that is 50 percent higher than the advanced SRC system to satisfy the factory low pressure steam demand for sugar and ethanol processing, which may again affect its ability to provide steam and electricity during the off-season. For the Indonesian sugar factory, the annual revenue potential of the BIGCC system is US$14 million per year, approximately 50 percent higher than that of the advanced SRC system (electricity sale rate: US$45/MsWh; carbon credit price: US$13.60). BIGCC technology is still in an early stage of development and there are no commercial systems in sugar factories, so an advanced SRC system may be a more suitable option in the near future.

Valdes, C.F., et al., [7] presents the results of co-gasification of Sub-bituminous coal type A with palm kernel shell in a fluidized bed gasifier to meet the energy requirements for baking 300 tons/day of bricks in a tunnel kiln. Standardized operation of the co-gasification process of the SubbA coal - PKS 90/10 wt.% mixture was confirmed for a 24 h run. The reactor has the capacity to process up to 700 kg/h of the mixture, using air and an air/steam as the gasifying agent at 800 °C, with an equivalent ratio of air/fuel (ER) between 0.5 and 0.7 and a steam/fuel ratio of 0.2. The product syngas had a HHV of 5.0 MJ/Nm^3 that efficiently substitutes and the traditional use of pulverized coal by means of carbo-jets

into the tunnel kiln without affecting the production process, while using a much cleaner gas to cook the bricks with lower emissions. This demonstrates the synergy existing in this coupling. Positive results of these experiments can enhance use of coal in a clean manner. This technology is fine enough to be implemented as a continuous energy supply to industrial processes that currently use traditional combustion for heat.

The proper use of alternative fuels and materials in the cement industry is essential for the planning and promotion of different methods that can decrease the environmental impacts, lower the consumption of energy and material resources, and reduce the economic costs of this industry. In the recent years, because of the great potential for the cement industry to save energy and reduce greenhouse gas emissions (GHG), many new researches associated with the promising approach of introducing waste materials as alternative fuels or sustainable raw materials into the cement manufacturing process have been developed. Uson, A.A., et al., [8] provide a literature review of these approaches. The analysis is mainly focused on the technical, economic, and environmental effects of the uses of five solid wastes, namely, municipal solid waste (MSW), meat and bone animal meal (MBM), sewage sludge (SS), biomass, and end-of-life tyres (ELT), in the cement industry.

Kenya is a leading country in the production and trade of black CTC tea in the world. Every year the country produces in excess of 300 million kilograms of made tea with KTDA accounting for about 60% of this. But this production calls for huge supply of both thermal and electrical power to the tea factories to meet their process heat and electrical power demands. About 15% of total energy required in tea production is electrical while thermal energy requirements is about 85%. Electrical power demand is met primarily from the national grid while process heat is met through own steam generation from combustion of biomass based fuels such as wood fuel, briquettes and also combustion of fuel oil in oil burning heaters. Operation of tea factories especially withering and drying, means there is always a constant demand for electrical and thermal energies in 1:6 ratio. This concurrent energy demand, mean that tea factories can install technically and economically feasible biomass based cogeneration units that expand steam through double stage turbine systems. The expansion of the steam results in quantifiable electrical power generation, while extraction of steam at lower pressures provides process steam for drying and withering process. Successful operation of Finlay's Saosa tea factory woodchip cogeneration plant in Kericho since 2009 shows that biomass cogeneration is a viable and feasible option for KTDA tea factories. Based on their current feedstock (biomass) consumption levels, the 58 KTDA tea factories have the potential to generate more than 30 MW electrical power and more than 264 MW of thermal power. Technologies like Combined Heat and Power systems help in improving fuel use efficiency at the same time help tea factories achieve their pollution control. Patrick, K.M., [9] presents a discussion on energy utilization in the tea factories, quantifies the cogeneration potential that is available in the tea factories based on current energy utilization and goes ahead to present possible lifetime cost of power generated.

Many gasification plants use scrubber systems for the removal of tars from producer gas. The cost of the scrubber liquid represents a considerable part of the operating cost, which could be decreased by regenerating the spent scrubber liquid by separating it from ash residues and heavy tars. Malek, L., et al., [10] regenerate different types of spent scrubber liquids using a centrifuge. The effect of centrifugation time (1.5-10 min) and sample temperature (50-90°C) on the separation efficiency is studied. Based on the results, the separation of tars from the scrubber liquids can be ranked as follows: diesel > RME > linoleic acid > linseed oil > rapeseed oil > motor oil. This ranking correlates to the viscosity of the different scrubber liquids, with the separation efficiency increasing with decreasing scrubber liquid viscosity. The best separation efficiency was achieved for scrubber liquids with low viscosity at 90°C and 10 min of centrifugation time. The results obtained indicate that centrifugation can be used for the regeneration of spent scrubber liquid.

Rathore, N.S., et al., [11] address the design, performance and economic evaluation of biomass based open core downdraft gasifier for industrial process heat application. The gasifier is having feed rate as 90 kg/h and producing about 850 MJ/h of heat. The gasifier has been installed in M/S Phosphate India Pvt. Limited, Udaipur (27° 42' N, 75° 33' E) for heating and concentrating phosphoric acid. The system is in position to save 20 L of light diesel oil per hour. The techno economics of the designed system is also presented in the paper.

3. CONCLUSION

From the current study it is observed that biomass is in abundant use in almost all processing sectors around the globe. The following are some of the conclusions drawn from the review:

- Once fully commercialized, gasification-based pulp mill bio-refinery technologies offer the potential for attractive investment returns and, if implemented widely, there might be significant energy and environmental benefits to the United States.

- The biomass source generated from the olive industry wastes could be a feasible option in gasification technology applied to distribute generation. Electric efficiency of 14%, overall efficiency of 36% and high gasification efficiencies could be expected to be achieved if a small-scale plant based on a downdraft gasifier and a gas engine connected to the grid is installed.
- For the Indonesian sugar factory, the annual revenue potential of the BIGCC system is US$14 million per year, which is approximately 50 percent higher than that of the advanced SRC system. BIGCC technology is still in an early stage of development and there are no commercial systems in sugar factories, so an advanced SRC system may be a more suitable option in the near future.
- The proper use of alternative fuels and materials in the cement industry is essential for the planning and promotion of different methods that can decrease the environmental impacts, lower the consumption of energy and material resources, and reduce the economic costs of this industry.
- There is technically and economically viable potential for biomass cogeneration in KTDA tea factories. The most feasible system to be installed in the tea factories is a 750 kW_e steam turbine cogeneration system. Such a system would be able to generate enough electricity to power the factory machinery and also provide enough process heat for tea production. however, implementation of the same requires an upgradation of the steam generation equipments.

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