Abstract

The rapid depletion of fossil fuel resources together with the focus on limiting greenhouse gas emissions have led to an increased effort in the development of sustainable, alternative and renewable energy conversion processes. Hydrogen, a non-polluting, secondary energy carrier, can be used as an alternative fuel for future use in hydrogen fuel cells and combustion engines. Biomass is considered as a solution to this problem, from which hydrogen can be produced due to its CO_2 neutrality, and lower emission of nitrogen oxides (NO_x) and sulphur dioxide (SO_2) during combustion. Hydrogen production from biomass has attracted great attention as an alternative fuel for future use to replace a significant proportion of fossil fuels. Traditional Biomass combustion based technologies achieve low electrical efficiencies (20-25%) and therefore cannot compete with fossil fuels. Biomass gasification coupled with advanced power generation systems such as gas turbines or fuel cells offer much higher efficiencies. One of such technologies frequently used which allows an increase in the energetic effectiveness of the system along with the reduction in the emission of CO_2 is known as combined heat and power CHP) system where cogeneration of heat and power occurs simultaneously, with waste energy as a heat input to the cycle, mainly operated with organic fluids as working agents and called Organic Rankine Cycle (ORC) modules.

In order to substitute conventional energy, the proposed system where the high thermal energy carried out by the gasification products has been utilized to operate a combined heat and power system consisting of steam and organic rankine cycles is modeled and simulated using the ASPEN PLUS simulation package. The effects of various input parameters such as water to biomass ratio, mass flow rate, reactor temperature and type of biomass on the different output parameters such as methane, syngas, total combustible gas and hydrogen productions and

performance index have been studied. Gasification temperature has been optimized for maximum syngas production. With the help of simulation results suitable biomass material can be selected for maximum hydrogen production and power output under a given set of conditions.

Over the last couple of decades, there is an increasing number of waste heat sources which release enormous amount of heat into the environment, leading to serious environmental pollution. Exhaust gases from turbines and engines, and waste heat from industrial plant are some typical cases. In addition, there are abundant geothermal and solar energy sources available in the world waiting to be utilized. In order to utilize these resources of thermal energy, CHP system combined with refrigeration cycle, also known as Combined Cooling, Heat and Power (CCHP) system, have been explored for improving overall thermal energy conversion of the system, which can lead to reduction in fossil fuel consumption and alleviating environmental problems. Therefore, there is a need to analyze such a system which compromises of biomass as a fuel source combined with improved thermal conversion efficiency of the CCHP cycle.

The above mentioned CCHP cycle has been theoretically assessed for selected biomass materials using Aspen Plus simulator package. The proposed novel biomass gasification based tetra-generation system for syngas, heating, cooling and power generations has been analyzed in three configurations. These are namely, steam Rankine cycle with organic Rankine Cycle and ejector refrigeration cycle (Cycle-1), binary Rankine cycle with ejector refrigeration cycle (Cycle-2) and steam Rankine cycle with combined power ejector refrigeration cycle (Cycle-3). Instead of using the chemical energy of the gasification products, the systems use the thermal energy of the gasification products to operate the Rankine and Refrigeration cycles in all the three configurations. The main gasification product obtained from the system is known as Syngas (a mixture of hydrogen and carbon monoxide gas) which has the potential for various domestic applications such as cooking. The effects of different operating parameters such as water to biomass ratio, total biomass-water mass flow rate, mass flow rate of refrigerant, generator pressure, gasification temperature and types of biomass material have been studied on the syngas and hydrogen yields, as well as coefficient of performance and overall performance index of the system.

The organization of six chapters in the thesis is presented next.

In **chapter one**, a brief background of the gasification process along with motivation for the present work is discussed.

In **chapter two**, the literature review is presented.

In **chapter three,** the modified biomass gasification system integrated with the steam power cycle and ORC operated in series has been proposed to increase performance index as well as syngas production. Performances of ten different biomass materials which are abundantly available in India, have been compared in the context of syngas and hydrogen production, and also on the basis of heat (air and water heating systems) and power generated from steam Rankine cycle and organic Rankine cycle. Interesting observations are made about the performance index of the CHP system and syngas production from the gasification system.

In **chapter four,** the previously mentioned CHP system has been combined with refrigeration cycle to model a Combined Cooling, Heat and Power (CCHP) system for two biomass materials namely, leather waste (produces maximum syngas) and paper mill sludge cake (gives highest performance index), out of ten previously selected biomass materials. Sensitivity analyses of various thermodynamic parameters such as coefficient of performance, refrigeration effect and overall performance index of all the three configurations of the system have been carried out to conclude which configuration is better under which set of input conditions.

In **Chapter Five**, three configurations, namely, a concentrating solar collector powered pre-heater unit integrated with a conventional biomass gasification system, a Solar ORC system integrated with SOEC (co-electrolysis) and a wind powered variant of the above mentioned systems has been analyzed. Since gasification is a mildly endothermic process some amount of air must be inlet into the gasifier so as to make the gasification process self sufficient as reported in the previous work done by the authors. This study concludes that inclusion of Solar energy reduces the amount of air needed in the gasifier and thus reduces the amount of carbon dioxide produced. The objective of work in this chapter is to study the effect of different operating parameters (gasification temperature, solar irradiance, area of solar collector and water to biomass ratio) along with various performance parameters (production of syngas, methane, hydrogen, total combustible gas, Performance Index) on the three aforementioned configurations simulated via Aspen Plus simulator package.

In **Chapter Six**, the conclusions of the thesis are presented.