Chapter 6 Conclusions

6.1 Conclusions

The proposed CHP system is not only based on combined heat and power generation but also it is integrated with maximum syngas production criteria unlike other models of biomass gasification. Analysis of the model has been carried out with the help of four input parameters such as water-biomass ratio, total mass flow rate, temperature of gasification and ten different biomass materials along with five output parameters such as syngas, methane, performance index, hydrogen and total combustible gas. Firstly, it must be concluded that all gases including syngas, hydrogen, methane and total combustible gases were maximum under the conditions: WBR=0.2 and optimum gasification temperature for a specific total mass flow rate (TMF). For maximizing performance index (PI) of the model, water-biomass ratio (WBR) must be kept close to one i.e., both biomass and water mass flow rate must be equal. Additionally, the magnitude of PI can also be maximized by maximizing gasification temperature while maintaining constant TMF condition.

Secondly, another way for obtaining higher yields of all gases was that TMF must be as high as possible, whereas it should be noted that TMF has no effect on PI of the proposed model. Also, the total combustible gases yield has been found to be very much higher than that of CO_2 yield which indicates that it can be used for domestic purposes. Lastly, Leather waste should be used in the proposed model at relatively lower water-biomass ratio for maximum syngas and hydrogen production. Among ten different types of biomass materials, the least amount of hydrogen and syngas were produced for paper mill sludge cake. However, in regard to heat and power output, the highest performance index has been found for paper mill sludge cake at higher water-biomass ratio and the lowest has been found for cow manure and spent coffee, though cow manure is sufficiently available in India. Hence, the best performance in terms of heat and power output does not simultaneously ensure a good amount of biogas production. Therefore, a trade off is required between CHP and biogas production.

In the present scope of work, an assessment of three novel biomass gasification based combined heat, power and ejector refrigeration cycles have been proposed which have also been integrated with eco-friendly syngas production. Assessment of these cycles has been carried out for six input parameters such as WBR, two types of biomass material, gasification temperature, boiler pressure, mass flow rate of refrigerant and total mass flow rate of biomass and water (TMF) whereas COP, refrigeration effect (RE), syngas yield, hydrogen yield, and performance index (PI) have been considered as output parameters. First four output parameters such as COP, RE, syngas and hydrogen yield have been found to be higher for lower WBR. However, PI has been found to be more for higher WBR. Therefore, lower WBR is required for more syngas and hydrogen production. Hence, for the choice of appropriate WBR, a tradeoff is required between COP as well as RE and PI. It has been found that PI is independent of TMF, however, RE and COP have been found to be lower at higher TMF.

RE can be increased by setting the boiler pressure (40-100 bar) as high as possible and increasing the mass flow rate of the refrigerant in the cycle. Cycle-2 (binary ORC+ejector refrigeration cycle) must be selected for maximum RE for optimum gasification temperature range of more than 800K at a constant WBR. However, for the range of temperatures lower than 800K, Cycle-1(Steam rankine cycle+ ejector refrigeration cycle) must be preferred over Cycle-2. For achieving maximum COP, Cycle-2 must be prioritized with highest boiler pressure and lowest TMF (100 kg/h) for PMSC followed by LW. In this study, higher value of PI has been obtained for PMSC as compared to LW at WBR=0.4 whereas greater value of PI has been found for LW followed by PMSC at WBR=0.6 either for Cycle-1 or Cycle-2 at optimum gasification temperature. PI also increases with the increase of gasification temperature at constant TMF. For all the parameters, Cycle-3 (steam rankine cycle + combined power ejector refrigeration cycle) has been found to be the least effective when compared with other cycles. Among the two biomass materials considered, LW produces more syngas and hydrogen whereas PMSC generates higher refrigeration effect, COP and Performance Index.

Furthermore, in this thesis, 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 an integration of the wind power with the above mentioned systems to drive pumps has been proposed and analyzed. Since steam 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 chapter concludes that inclusion of solar energy reduces the amount of air needed in the gasifier and thus reduces the amount of carbon dioxide produced. Investigation of these cycles has been carried out by five input parameters such as WBR, Area of collector, Gasification temperature, sunlight hours and Biomass materials whereas PI, Syngas, Hydrogen, carbon dioxide and Air required in the gasifier have been taken as output parameters. syngas, carbon dioxide and hydrogen production first increases with gasification temperature but after reaching a maxima it starts to decrease whereas air required in the gasifier is directly proportional to the gasification temperature. PI has been found to increase with gasification temperature. Higher solar collector area produces more syngas and hydrogen whereas lower collector area generates more carbon dioxide. Thus, higher collector area is suitable for cycle-4 (solar assisted biomass gasification cycle). Maximum amount of syngas and hydrogen have been observed to generate at afternoon and forenoon (4-6 Sunlight hours) hours, and minimum carbon dioxide has been produced at noon hours also. Therefore, it has been recommended selecting this range of sunlight hours for both the cycles (cycle-4 and cycle-5). Finally, Cycle-6a and Cycle-6b must be chosen over cycle-4 and cycle-5 (SOEC cycle) in terms of PI, so it can be concluded employing wind energy in the proposed system increases the performance of the system.

Combined cooling, heat and power (CCHP) is a proven technology where steam Rankine cycle, organic Rankine cycle (ORC) and refrigeration cycle have already been integrated. The novelty of our research is that our combined heat and power(CHP) or combined cooling, heat and power system is based on biomass gasification where we also get syngas along with CHP or CCHP. However, when CHP/CCHP system has been developed based on steam gasification of biomass, air has also been supplied due to the fact that steam gasification is an endothermic process. Due to this production of CO_2 has been increased along with a substantial reduction in syngas production. Hence, to maintain environmental harmony integrating with an appreciable amount of syngas production, solar collector has been integrated with our CHP system for preheating purpose. However, considering the operational feasibility, we have not integrated solar collector with CCHP. Along with syngas, we also emphasize hydrogen production. For that purpose we have considered solar ORC to generate electricity and subsequent electrolysis of water by solId oxide electrolytic cell to produce hydrogen. We have not integrated our proposed solar ORC and solid oxide electrolytic cell with biomass gasification and refrigeration cycle due to the fact that the integrated system would not be operationally feasible and economically viable. Hence, our proposed system is sustainable for practical applications. However, technology readiness level

(TRL) of our proposed system is not enough for commercialization. In the future scope of work, we will develop an economic model for the market entry and further commercialization of our proposed system.

6.2 Future Scope of Work

The following tasks can further be carried out in line with the present work:

- Focus should be given to the use of Phase Change Material (PCM) as a thermal energy storage medium.
- Design of the parabolic trough solar collector can further be improved by including various Solar angles.
- The setup of the Proposed Solar assisted biomass gasifcation system can be developed.
- Reactions including sulfur and char can be incorporated into the system.
- Modeling of the wind turbine can be integrated to enhance the efficacy of the hybrid system.