Chapter-5

Conclusions and future work

In this thesis, we developed an experimental set to analyze the quality of producer gas so that it can be used as fuel together with conventional diesel to run the dual-fuelled diesel engine. A separate technique was used to filter the impurities present in producer gas like tar, ash and dust particles. In addition, an experiment was carried out on soybean methyl ester (biodiesel) to know the effect of storage time on its calorific value and emission at different blending ratios *B10, B20* and *B30* so that biodiesel can be used together with diesel and producer gas. A separate multi-stage filtration unit was designed and developed for eliminating the impurities left in the producer gas in the last stages of filtrating process before feeding the gas to the power generation unit. For this, the multi-stage filtration system has been investigated for regulating the pressure with minimum losses in the system. We developed a numerical model for selecting the best configuration of filter parameters. The main results of the thesis are discussed in the following section.

5.1 Main results

Followings are the main outcomes of the present work.

Quality of the producer gas is related to its consumption when used with conventional diesel fuel and it reflects in the unit energy production cost. It was observed that:

- For external load *1 kW* and *4 kW*, the unit energy production cost is Rs. 8.09 and Rs. 8.32 respectively, when only diesel as fuel is used.
- For external load *1 kW* and *4 kW*, the unit energy production cost is Rs. 7.26 and Rs. 6.68 respectively when diesel together with producer gas is used (producer gas obtained from wood). The unit energy production cost got decreased by Rs. 0.83 and Rs. 1.64 for external load *1 kW* and *4 kW* respectively, compared to diesel.
- For external load *1 kW* and *4 kW*, the unit energy production cost is Rs. 7.15 and Rs. 7.75 respectively when diesel together with producer gas was used (producer gas obtained from wood + 10 wt. % *CaO*). The unit energy production cost got decreased by Rs. 0.94 and Rs. 0.57 for external load *1 kW* and *4 kW* respectively, compared to diesel. In addition, while doing a comparison between wood and

wood 10 wt. % *CaO* at external loads *1 kW* and *4 kW*. The unit energy production cost got reduced by Rs. 0.11 and increased by Rs. 1.07 respectively.

- For the same external load of *1 kW* and *4 kW*, the unit energy production cost is Rs. 6.62 and Rs. 6.59 respectively when fuel diesel together with producer gas (producer gas obtained from coconut shell) was used. The unit energy production cost got reduced by Rs. 1.47 and Rs. 1. 73 for external load *1 kW* and *4 kW* respectively, compared to diesel.
- For external load *1 kW* and *4 kW*, the unit energy production cost is Rs. 6.50 and Rs. 6.97 respectively which belongs to fuel diesel together with producer gas (producer gas obtained from coconut shell + 10 wt. % *CaO*). The unit energy production cost got decreased by Rs. 1.59 and Rs. 1. 35 for external load *1 kW* and *4 kW* respectively, compared to diesel. In addition, while doing a comparison between coconut shell and coconut shell + 10 wt. % *CaO* at external loads *1 kW* and *4 kW*. The unit energy production cost got reduced by Rs. 0.12 and increased by Rs. 0.38 respectively.
- The uncertainty analysis has been done to address the deviation in observed data during experiments. The uncertainty for *4 kW* load for diesel fuel is 8 ± 0.81. For other fuels and loads it is mentioned in Table 2.14.

Tar reduction from the producer gas is done by mixing mineral calcium oxide as a catalyst with biomass feedstock through primary filtration method. The important observations are:

- The weight of tar was 0.154 *gm/min* and 0.0798 *gm/min* in the producer gas which is obtained from wood and wood + 10 wt. % *CaO* respectively. The difference in these weight gives the tar reduction, of 0.0742 *gm/min* or percentage of tar reduction is 48.18% at 850^{o}C.

- For coconut shell and coconut shell + 10 wt. % *CaO*, the tar weight is 0.125 *gm/min* and 0.116 *gm/min*. The difference in the weight gives the tar reduction, of 0.009 *gm/min* the percentage of tar reduction is 7.2% at 790^{o}C.
- Leith and Licht model gives the close results with experimental results.

Consumption of diesel is reduced by supplying producer gas together with diesel, but producer gas quality affected the diesel consumption, therefore, blending of biodiesel with conventional diesel play a vital role and fulfil the producer gas deficiency.

Followings are the key points which are associated with the biodiesel viscosity, storage time and emissions at different loads *0 kg, 2 kg, 4 kg, 6 kg, 8 kg, 10 kg, 12 kg* and different compression ratios 18:1, 17:1, 16:1, 15:1 at different blending ratios *B10, B20* and *B30.*

- The kinematic viscosity of the biodiesel increases with storage time. This is due to the formation of different oxidized products, including hydroperoxides and aldehydes, ketones etc.
- The calorific value of the biodiesel decreases slowly in the observational period 2 to 4 days, so storage time affect the calorific value of biodiesel.
- The carbon monoxide content in the emission decreases with the increase in the load, while the hydrocarbon content remains nearly constant. Nitrogen monoxide and carbon dioxide content increase with an increase in load to a particular point of maxima and then decreases with further increase in the load. The oxygen content shows exactly the opposite behaviour with respect to carbon dioxide. The nature of the emission curve for *B10, B20* and *B30* curve remains similar for different loads at various compression ratios.

Effect of various hole shapes such as circular, square, triangular and hexagonal perforated filters have been investigated to be used in the filtration unit. Following are the main

observations:

- Square holes in the perforated filter performs better than other type of holes such a circular, triangular and hexagonal. However, a single circular hole shows lower pressure loss coefficient or Euler number variation compared to other type of filters.
- For filtration unit with constant porosity, number of perforated plates plays a significant role in controlling overall pressure loss coefficient than thickness ratio.
- Four new correlations are developed for perforation shapes with circular, square, triangular and hexagonal holes. The correlation has the form: $Eu = a(N)^b(t/d_h)^c$ where *a*, *b* and *c* are constants
- The predicted values of Euler number agree within 4% accuracy with the numerical data.

5.2 Future work

Future research could focus on the effect of various coatings on filter performance with different perforation shapes. We hope that data presented in the thesis would help researchers in developing efficient designs of multistage filters for effective utilization of gases produced from biomass materials.

List of publications from thesis work

International Journals:

1. Sunil Kumar, Amit Kumar, and O. P. Singh, "Multi-stage filter designs for a gasifier system," International Journal of Recent Technology and Engineering (IJRTE), vol. 8, Issue-4, November 2019. pp. 12612-12621, ISSN: 2277-3878 (Online), Nov. 2019. (Scopus indexed)
2. Sunil Kumar and S. K. Shukla, "Study of degradation of quality of soyabean biodiesel with storage time and its emissions on various loads," Materials Today: Proceedings, vol. 5, Issue- 11, part- 2, pp. 23177–23192, 2018. (Scopus indexed)
3. Sunil Kumar and S. K. Shukla, "Performance of cyclone separator for syngas production in downdraft gasifier," Advances in Energy Research, vol. 4, No. 3, pp. 223-237, 2016. (ESCI indexed)
4. Sunil Kumar and S. K. Shukla, "A review on recent gasification methods for biomethane gas production," International Journal of Energy Engineering, vol. 6 (1A), pp. 32-43, 2016. DOI: 10.5923/s.ijee.201601.05.
5. Sunil Kumar, Kunal Kanoi, Shweta Kumari, and S. K. Shukla, "An investigation on tar reduction in producer gas in downdraft gasifier system," Journal of solid waste technology and management, vol. 42, Issue 1, pp. 721-729. 2016.

International conferences:

1. Sunil Kumar and S. K. Shukla, "Analysis of different feedstock in downdraft gasifier system used in diesel engine in dual fuel mode," International Conference on Environmental Systems and Sustainable Development (ESSD), held on January 15- 16, 2016, at Chandmal Tarachand Bora College, Shirur, Pune, India, vol. 2, issue- 7 (Special Issue), 2016.

2. Sunil Kumar and S. K. Shukla, “A review on wood downdraft gasifier plant design for biomethane gas production,” International Conference on Energy Systems and Applications (ICESA 2015), held on October 30 – November 01, 2015, at Dr. D. Y. Patil Institute of Engineering and Technology, Pune, India, 2015.
3. S. K. Shukla, Sunil Kumar, N.V. Rahul Sharma and Arun Kumar, “Installation and experiments on 14 kW gasifier system,” International Conference on Industrial Instrumentation and Control (ICIC), held on May 28-30, 2015 at College of Engineering Pune, India, 2015.