Chapter 5 CONCLUSIONS AND FUTURE RECOMMENDATIONS

Lignocellulosic waste is recalcitrant due to the presence of a complex cell wall that is composed of interlinking of lignin, cellulose and hemicellulose. Therefore, a pretreatment step is necessary to break the recalcitrance and increase the accessibility of the substrate to microorganisms. The biogas production is highly dependent on lignin degradation. The fungal species *P. chrysosporium* and *P. ostreatus* were employed to degrade the lignin in the biological treatment of sawdust. NaOH treatment, alone and in combination with thermal treatment was also used to decrease the lignin content from sawdust. The hydrolysates of the treated and untreated samples were examined for glucose, phenolic content, volatile fatty acid (VFA) and sCOD. The effect of chemical, thermal, biological and thermo-chemical treatment on biogas production from OFMSW was estimated. The thermo-chemical treatment (5 g/L NaOH at 180 °C for 1 h) significantly increased the sCOD (96.2 %) and VFA content (138.1 %) as compared to the untreated sample. However, the fungal strains *P. chrysosporium* and *P. ostreatus* had little effect on sCOD and VFA values. It is noteworthy that the fungal strains were found to be capable of degrading phenolic content that is a benefit over chemical treatment, as chemical treatment resulted in the production of phenolic compounds. The effect of process parameters for biogas production was also considered and co-digestion was optimised for temperature, pH, and S/I ratio using RSM methodology. The salient conclusions out of this research work have been summarised and recommendations of further work are also suggested in this chapter.

5.1 Conclusions

- The *Tectona grandis* sawdust was found to contain a high amount of lignin of 29.1 % (Section 4.1).

- *P. chrysosporium* reduced the lignin 27.5 % more efficiently than *P. ostreatus* as described in section 4.2.1.
- In the chemical treatment of sawdust from different reagents, NaOH had the best potential to alter the cell wall structure to increase the sCOD and phenolic content (Section 4.2.2).
- The glucose concentration was higher in all the treated sawdust samples as compared to the untreated one. However, the degradation of glucose was occurred at a high NaOH concentration of more than 2 % (Section 4.2.4).
- The phenolic content, VFA and sCOD content were increased by increasing the NaOH concentration (Section 4.2.3).
- NaOH-autoclave treatment was best among all to disrupt the sawdust structure. The 10 % NaOH-autoclave (90 min) significantly reduced the lignin by 58.6 % (Section 4.2.9).
- The Crystallinity index was increased from 66.37 to 74.13 % after treatment indicating the removal of amorphous material like lignin and hemicelluloses (Section 4.2.7).
- SEM and FTIR analysis also confirmed the destructive cell wall due to pretreatment (Section 4.2.8 and 4.2.6, respectively).
- The biogas yield of the treated sample (10 % NaOH-90 min autoclave) was increased by 103.5 % as compared to the untreated sample (Section 4.3.1).
- Biogas yield after optimised NaOH-autoclave treatment was 289 NmL/gVS in 40days of the digestion period (Section 4.3.1).
- For OFMSW, the phenolic compound concentration was found to depend on the NaOH concentration more than temperature and time (Section 4.9.1).

- Thermal and thermo-chemical pretreatment had potential to disorganise the OFMSW structure and increase the biogas production (Section 4.5.6).
- Biological treatment resulted in less biogas production (303 Nml/gVS) as compared to other treatment methods. Moreover, *P. chrysosporium* treated OFMSW resulted in 13.9 % more biogas production than *P. ostreatus* (Section 4.5.6).
- The RSM optimised value of influencing parameters, NaOH dose, temperature and time for chemical and thermo-chemical treatment was 18.4 g/L, 36.05 ℃, 72 h and 4.72 g/L, 180 ℃, 30 min, respectively (Section 4.6.4 and 4.9.4).
- The cumulative biogas yield from chemically and thermo-chemically treated OFMSW at optimised condition was 465.67 and 529 NmL/gVS, respectively, that was 125 % and 149.5 % higher as compared to untreated OFMSW, respectively (Section 4.7 and 4.10.1, respectively).
- The modified Gompertz model was better fitted than the first-order model based on less RMSE value in experimental data of biogas production of both chemical and thermo-chemical pretreatment (section 4.8.3 and 4.10.2).
- The mixture of OFMSW-SS at the ratio of 4/1 was selected for the co-digestion as it contained a suitable C/N ratio (24.2) as described in section 4.11.2.
- The digestion period of the substrate was decreased with the increasing temperature (Table 4.25).
- The lag phase was increased with respect to an increase in the S/I ratio and a decrease in pH (Section 4.11.8).
- The highest lag phase of 8 days was found at S/I ratio 1.5 gVS/gVS, temperature 45℃ and pH 6.5. The lowest lag phase of 1 day was found at the S/I ratio 0.3 and pH 7, 7.5 (Section 4.11.8).

- The highest and lowest digestion time was observed at 30 and 60°C, respectively (Section 4.11.8).
- The optimum value of S/I ratio, temperature and pH achieved from RSM was 0.84 gVS/gVS, 43.97 °C and 7.07, respectively. The biogas production at this condition of anaerobic co-digestion was 626 NmL/gVS (Section 4.11.6 and 4.11.7).
- The methane concentration achieved was in the range of 60.27-15.78 % throughout the digestion period (Section 4.11.10).
- Manure produced from anaerobic co-digestion was found to be a good source of nitrogen (4.4 %) and potassium (2.4 %, section 4.11.10).
- The OFMSW has better biodegradability than sawdust and can produce more biogas than sawdust as comparing the result of anaerobic digestion of both substrates. It can effectively be used as mono-digestion or co-digestion to produce a significant amount of biogas.

5.2 Recommendations for future work

- The combination of pretreatment techniques for biogas yield from sawdust and OFMSW can be done.
- The study of biogas production can be extended to the different modes of reactor operation such as semi-continuous, continuous, etc.
- Co-digestion of sawdust and OFMSW with different wastes can be explored.
- The enrichment of biogas can be done.
- The work can be extended to the pilot plant level for the development of an efficient biogas production system.

5.3 Limitations of biogas production

- Biogas production is highly dependent on temperature. Therefore, this technology is not feasible for colder climates.
- The chemical pretreatment done on lignocellulosic waste produces wastewater which needs to be neutralised.
- The large consumption of water in wet digestion, biomass storage and transportation also makes the process challenging on an industrial scale.
- As biogas doesn't contain pure methane, up-gradation and purification of biogas are essential before using it as a transportation fuel.