Chapter 5: Conclusion and Future work

Conclusion section is categorised into two part wherein first part deals with the overall conclusion obtained from the numerical modelling and simulation. Second part includes the concluding specific statement pertaining to the experimental section.

The present work , comprising five chapters, has been made with this motivation to emphasize on various issues related to the possibilities , problem identification, and prospects of utilizing gasification technique in better way so that the infrastructural problems of fuel oil scarcity and environment degradation could be squarely met.

Chapter 1 discusses the practical importance of the problems highlighting the state of art and scope of the present work: environment pollution and human health, Biomass as alternative fuel, general performance of downdraft gasifier and dual fuel fuel engine, Simulation of complete gasification plant and RSM based optimization. The work is then divided into distinct parts and is described in the four remaining chapters of the thesis as follows:

- Chapter 2, Literature review
- Chapter 3, Materials and Methodology (Numerical + Experimental)
- Chapter 4, Results and discussion (Numerical + Experimental)
- Chapter 5, Conclusions.

In Chapter 2, a brief review of existing literature on both the modelling and the experimental work has been described. Complete literature survey has been tabulated in the four column wherein first column depicts different types of biomass taken for the investigation. Second column denotes the technical specifications of the gasifier taken for the experiment. Third column depicts the variable operating conditions taken for the analysis. Fourth column depicts the relevant research findings of the respected investigations. These research findings are the main novelty of the published research paper

Chapter 3 discusses the materials and methodology adopted for the present work. It has been categorised into three subsections. First section deals with the methodology adopted for the Numerical simulation, the second subsection describes the material, and the experimental methodology adopted for the completion of the experimental investigations and the third subsection deals with the optimization technique methodology adopted for the investigation

Chapter 4 deals with the results and discussion section. This section is categorized into two subsections. First sections deals with the result and discussion analysis pertaining to the numerical and modelling analysis part and then second subsection describes the result and discussion of the experimental investigations.

In Chapter 5, conclusions and scope of the future work have been presented.

5.1 Numerical simulation work conclusion

Prediction and multi-objective optimization of the variable gasification performance parameters by integrating ASPEN Plus with Response surface methodology (RSM) using biomass or non woody biomass fuel was investigated in this thesis work. The model was calibrated and validated using multiple biomass (Hardwood chip, Municipal solid waste, grape pomace, rapestraw pellet, softwood pellet) from the literature. Sensitivity and error analysis was performed. Temperature, equivalence ratio, moisture content, steam/plastic ratio was selected as the decision variables and the response output was selected as producer gas composition and gasification characteristics. An optimal working range was obtained to achieve the best possible outputs using RSM. More independent parameters like moisture content, gasifier reactor design can be adopted for the optimization study in the future work. Gasification using torrefied biomass and plastic waste can also be simulated using ASPEN PLUS and optimized using RSM in the further investigation.

The following overall numerical work conclusions can be concluded from the investigation done in this present study

- A comprehensive steady-state stoichiometric kinetic free equilibrium based robust model of biomass gasifier was developed using ASPEN PLUS simulator.
- The model is capable of estimating syngas compositions and gasifier performance under variable operating conditions. Model validation was done and found that results acquired in the present study are in good agreement with the experimental result
- Sensitivity analysis was performed in which the influence of variable gasification temperature, variable equivalence ratio (ER) on the syngas composition, gas yield, cold gas efficiency, and the higher heating value (HHV) was quantified.
- A highly accurate robust regression model has been attained from the ANOVA tool for estimating hydrogen concentration, cold gas efficiency, and higher heating value.
- RSM has been employed for the multi-objective optimizations of the variable gasification parameter wherein Central composite design (CCD) is adopted
- RSM optimizer of biomass air gasification fuelled with Syzygium cumini biomass estimates that the optimal magnitude of H_2, CGE, and HHV is 0.1, 25.23%, and 3.96 MJ/kg respectively corresponding to temperature at 887.879^{0}C and equivalence ratio 0.32.
- It is recommended that the optimal range of gasification temperatures should be around (750-850)^{0}C for HWC, (700-830)^{0}C for SWP, (800-900)^{0}C for PLP, and (800-950)^{0}C for RSP. The equivalence ratio should be around 0.2 for all four biomasses. further increase in ER led to a decrease in the magnitude of CO and H_2 as well as HHV of syngas.

- The optimized magnitude of moisture content for HWC, SWP, PLP, and RSP are 12.52%, 6.66%, 14.79%, and 17.95% respectively.
- Temperature 1023.43^{0}C, equivalence ratio 0.18, and S/P 0.98 are the optimal independent working parameters for steam gasification of low density plastic waste.
- The ideal values of responses CO, H_2, CGE, and HHV, according to the RSM optimizer, are 0.24, 0.51, 80.61%, and 9.7 MJ/Nm^3, respectively for steam gasification of low density plastic waste.
- The most important factor in increasing syngas CGE is gasification temperature, followed by S/P and ER.
- The optimized independent operating conditions for plasma gasifier are temperature 1560.60^{0}C, equivalence ratio 0.1, and S/B 0.99.
- The ideal values of responses H_2, CGE, and HHV, according to the RSM optimizer, are 0.43, 89.95 percent, and 7.49 MJ/Nm^3, respectively.
- Injecting steam as a gasifying agent enhances the hydrogen concentration in the syngas
- ER is the most influential parameter in enhancing the CGE of syngas followed by S/B and temperature.

5.2 Experimental work conclusion

Experimental study aims to optimize three operating parameters: equivalence ratio, compression ratio, and engine load. The RSM optimization technique is used to optimize seven output responses, including efficiency and emission parameters, namely BP, BTE, BSFC, CO, UHC, CO2, and NOx. The optimization of input variables is mainly attributed to maximize brake power (BP), brake thermal efficiency (BTE), and minimize the brake specific fuel consumption (BSFC) and exhaust emission (CO, UHC, CO_2, and NO_x).For the production of producer gas, Biomass/Low-grade coal was chosen. On the dual-fuel VCR CI engine, a total of 48 experimental trials were conducted. With a confidence interval of 95%, regression models built from ANOVA results are found to be highly accurate in predicting performance response variables.

The following overall experimental work conclusions can be concluded from the investigation done in this present study

- The maximum amount of fuel saved during the gasification of jamun wood was 9.69%, 10.09%, 19.6%, and 45.9% at the compression ratio 15, 16, 17 and 18 respectively
- Thermal stability was achieved in the range of (10-30 min) after the start of gasification experiment as temperature profile was somewhat linear in this time range.
- Maximum amount of diesel that was saved at 100%, 75%, 50% and 25% throttle opening position was 19.04%, 53.52%, 31.91% and 27.81% respectively
- The optimum equivalence ratio was observed at 0.36 and corresponding throttle was 75% opened. The diesel saving increased to 53.52% at the 2.4 kw condition.
- The Equivalence ratio of the gasifier determines a major portion of the engine's emission characteristics in the gasification of low grade coal.

- The ideal values of independent parameters in the gasification of low grade coal (equivalence ratio, compression ratio, and engine load), as determined by the response optimizer, are 0.12, 17.01, and 12 kg, respectively.
- The optimal values for BP, BTE, BSFC, CO, UHC, CO2, and NO are 3.54 kW, 28.23 percent, 0.38 kg/kWh, 0.0231%(percent vol), 4.2539 (ppm), 0.9569 (vol %), and 9.6958 ppm, respectively.
- The experimental investigation has been successfully conducted to run a triple fulled mode CI engine with producer gas generated from Mahua tree waste and blended with safflower-based biodiesel and diesel
- RSM model is a valuable tool for identifying the engine operating settings that work well for increasing engine performance and emissions responses.
- The optimal values for the engine running on triple fuel mode (compression ratio, equivalence ratio, and engine load) are 17.2, 0.2, and 73.4 % respectively.
- 27.57%, 3.31 kg/kWh, 2.49 kW, 0.0081 % (vol percent), 1.53 (vol percent), 8.60 (ppm) and 182.91 (ppm) are the best amounts for BTE, BSFC, BP, CO, CO2, UHC, and NOx, correspondingly.
- This study concludes that the CI engine can run effectively and efficiently with triple fuel mode (PG + Biodiesel + Diesel) with optimized operating conditions.
- The optimal values of independent parameters, such as equivalence ratio, compression ratio, and engine load, are 0.12, 16, and 12 kg in the case of coconut gasification, respectively.

- 3.52 kW, 26.41 %, 0.48 kg/kWh, 0.0042 percent (% vol), 15.15 (ppm), 1.27 (vol %), and 2.94 ppm are the optimum values for BP, BTE, BSFC, CO, UHC, CO2, and NO, respectively for the gasification of coconut shell.
- The magnitude for the independent parameters Equivalence ratio 0.12, compression ratio 16, and engine load 12 kg that was optimised.
- The cumulative composite desirability observed was around 0.9520.

Conclusively, it was found that PG fuel generation from different biomass waste feed material and non-woody material have significant potential to substitute conventional fuel like diesel through Gasifier-Engine integration system. Further, this study will provide a base for the end-users and researchers to adopt a gasifier-IC engine integration system, which will provide a feasible approach toward utilizing low-grade hard coke coal and biomass waste in air gasification through a downdraft gasifier.

5.3 Scope for Future work

The experimental and numerical investigations carried out in this research activity have provided a basis to address the fuel dependence of gas engine performance and a generic methodology to address alternate fuels in a systematic manner. Future work based on the generic scenario of producer gas fuelled operation of an adapted natural gas engine with emphasis on improving the gasification efficiency and fuel conversion efficiency and improving the versatility of the developed models can lead to new areas of research as described below.

- Co-gasification of coal having high content of ash and different samples of biomass has the potential to become a future method of evaluating LGC and biomass.
- Development of highly efficient modified downdraft gasifier which can able to produce very high quality of Producer gas with minimum magnitude of tar content inside the reactor.
- Development of catalytic integrated air-steam gasifier for the gasification of agriculture waste and valorization of gasified fly ash on concrete work will be the future scope of the present work.
- Prediction of tar and char in the numerical modelling of gasification can be the advancement in the numerical technique of gasification
- This study is first step for giving the direction in the gasification technique, but does not consider environmental and social aspects and these can be considered in future.