CHAPTER 5

SUMMARY OF CONCLUSIONS AND SUGGESTIONS FOR FUTURE WORK

India is a world's second largest paddy producer. It produces over 90 million tonnes of paddy. About 20 million tonnes of rice husk is generated as by-product when the paddy is milled into rice. There are over 1,10,000 rice mills in India, 60,000 mills in Indonesia and 40,000 mills in Thailand. The present experimental study is focused on fluidized bed rice husk gasification for power generation. The gas generated in the fluidized bed gasifier is cleaned and cooled and used in diesel engine in dual fuel mode to generate electricity. The conclusions of the present work are summarised below:

5.1 SUMMARY OF CONCLUSIONS

5.1.1 Fluidization and Mixing Behaviour of rice husk

It is difficult to fluidize the rice husk due to its odd shape, low density and abrasive surface. Rice husk particles require high superficial velocities to fluidize because of inter-particle friction due to their rough abrasive surfaces. The minimum fluidization velocity of rice husk is approximately estimated as
50 cm/s from its pressure drop curve. At low fluidization velocities (less than 80 cm/s) frequent plugging and channelling are observed.

The fluidization behaviour of rice husk is improved when it is mixed with sand to form a multisolid system. When the weight percentage of husk is less than 3%, the mixture exhibits good aggregative fluidization. The mixing of rice husk with sand is more uniform in the into-bed feeding than in the over-bed feeding. It is also found to be quicker in the into-bed feeding.

The minimum fluidization velocity of rice husk ash is measured as 22 cm/s. The mixture of sand and ash exhibits good aggregative fluidization if the weight percentage of ash is less than 30%. The ash particles can be selectively elutriated out of the bed by properly choosing the operating velocity.

5.1.2 Agglomeration Studies on Rice Husk and other Agricultural Residues.

In gasification atmosphere, no agglomeration of rice husk ash is encountered in the tested temperature range (upto 1020°C) in the controlled fluidized bed agglomeration test with both lime and quartz bed material. However, initial agglomeration is encountered at 1009°C during the combustion of rice husk in quartz bed material. It indicates the suitability of gasification process for conversion of rice husk over combustion process.

The initial deformation temperature for rice husk predicted by ASTM ash fusion test is more than 1600°C in both combustion and reducing atmosphere. The rigid cage-like structure of the ash sample may not permit the deformation of the cone in the ASTM ash fusion test unless otherwise the silica itself melts down and thus indicating very high ash deformation temperature. It shows the poor ability of the ASTM ash fusion test to accurately predict the
agglomeration behaviour of biomass fuels, particularly fuels like rice husk, which has high ash content (16-23%) with more than 95% silica.

The agglomeration resistance of cane trash and olive flesh are poor. The agglomeration of bagasse is not encountered in the tested temperature range (up to 1020°C). It can be used as supplementary or alternative fuel with rice husk. It may require pre-processing to enable its smooth feeding into the bed.

5.2.3 Fluidized Bed Gasification of Rice Husk

The gasification experiments established that the bed temperature and fluidization behaviour are the two main parameters affecting the performance of the gasifier. The gasification temperature can be controlled by adjusting the equivalence ratio. For instance, the bed temperature is increased from 720 to 950°C by increasing the equivalence ratio from 0.26 to 0.52, for 16 kg/h husk flow rate. An isothermal condition of the bed can be achieved by controlling the equivalence ratio so as to have a good aggregative fluidization.

The lab scale reactor of 150 mm diameter is found to gasify 12 to 20 kg of rice husk per hour. The quality of the gas and the cold gas efficiency are maximum for the rice husk flow rate of 16 kg/h. The LHV of the gas is found to increase with the temperature to reach a maximum of 5.6 MJ/Nm³ at 780°C for the fuel flow rate of 16 kg/h. Producer gas with LHV of 5 to 5.6 MJ/Nm³ is produced in the temperature range of 730 to 840°C.

The producer gas productivity is increased from 1.14 to 2.15 Nm³/kg if the temperature is increased from 700 to 900°C. A maximum carbon conversion efficiency of 81.6% is achieved in the lab scale gasifier. A maximum cold gas efficiency of 66% is achieved at 780°C. It is more than 60% in the temperature range of 750 to 850°C. It may be noted that it is considerably higher than that
achieved in down draft rice husk gasifiers, which is in the order of 50% (UNDP, 1990).

Tar content in the producer gas is strongly influenced by the bed temperature. As the temperature is increased from 700 to 950°C, the tar content decreased from 13.4 g/Nm³ to 2.73 g/Nm³ as per solid phase extraction method. The tar content is decreased by about 10% if the static bed height is decreased from 200 to 300 mm. Other than this, the particle size and bed height do not affect the gasifier performance significantly in the particle size range of 0.463 to 0.655 mm and the bed height range of 200 to 300 mm.

5.2.4 Dual fuel operation of Diesel Engine

The cleaned producer gas from the gasifier is used as dual fuel with pilot injection of diesel for ignition in a 7.5 kW diesel engine coupled with an electrical generator. A maximum diesel replacement of 73% is achieved without any major modifications. The exhaust gas temperature is about 200°C higher in dual fuel mode compared to that in full diesel mode. The concentration of carbon monoxide is relatively higher and hydrocarbon is lower in the engine exhaust gas in the dual fuel mode. The loss of efficiency of the diesel engine due to the operation on dual fuel is about 2 to 5%. The overall efficiency of the gasifier-engine system is 17.8%. The performance of the engine can further be improved by providing a well-designed gas to air mixture and properly tuning the fuel injection.

5.2.5 Pilot Plant Fluidized Bed Gasifier

The bed temperature could be controlled by changing the air to fuel ratio as in the case of lab model. The stable gasification temperature (within ±5°C)
can be achieved in the fuel flow rate of 100 to 130 kg/h. When the area is increased by 9 times, the fuel flow rate is increased by about 6 to 8 times. The gasifier is found to generate gas with LHV of 4.7 to 5.8 MJ/Nm$^3$ in the temperature range of 760 to 810°C.

The measured maximum values of LHV of gas, carbon conversion efficiency and cold gas efficiency are 5.8 MJ/Nm$^3$, 83% and 68% respectively. The improved performance of the pilot plant can be attributed to better fluidization and mixing in the larger size reactor than in the small lab reactor. The operating experience of pilot plant shows that the fluidized bed gasifier can be confidently scaled up, at least in the studied size range of 150 to 450mm diameter.

5.2.6 Economic Analysis

The results of economic analysis demonstrate a favourable case for the installation of gasifier-engine system for generating power by utilising the surplus husk. The fluidized bed gasifier and engine system can be installed in rice mills, which are already connected to the grid. The mill can be operated by grid power in case of any problem in the gasification system. This is advisable till the reliability of the system is established in the field. The pay back period is less than 3 years for the rice mills of at least 4 tons per hour capacity, for which price of the gasification system is less than Rs.9000/- per kW$_e$ under normal conditions.

In the remote areas where the grid electricity is not available, the diesel engine used for powering the rice mill can be replaced by gasifier-diesel engine system as it results in the savings of 10 to 34% under normal conditions, even without considering the financial incentives.
5.2 SUGGESTION FOR FURTHER WORK

The following suggestions are proposed for further improvement in the present work.

1. Steam is generated in the rice mill for parboiling the paddy. The present work can be extended to steam gasification, in which the steam can be used as fluidization and gasification medium. This can generate producer gas with higher heating value.

2. The work can be extended to study the effect of free board and transport disengagement height on gas composition, carbon conversion efficiency and tar emission.

3. The present investigation can be extended to study the effect of other type of distributor plates.

4. The effect of fuel feeding in gasification at various levels with respect to different bed heights can be studied.

5. Gas conditioning system should be optimised so as to improve the particle and tar cleaning efficiency.

6. Catalytic bed materials like dolomite and limestone can be tried as bed material to study its effect on tar content in the producer gas.

7. Mixing unit for the preparation of proper producer gas and air mixture can be used to improve the performance of the engine on dual fuel mode.

8. The value-added by-product like silica can be recovered from the rice husk ash. It can further improve the economic viability of the system.
9. The exit water from the water scrubber contains all the water-soluble components in the raw producer gas stream. Consequently, an effluent treatment plant should be designed and constructed to treat this water to make it environmentally acceptable.

10. A systematic and long term research is required to optimise the gasifier-engine systems.

11. The rice husk from various mills in the same locality can be collected to a central place to utilise them in a bigger size gasification system. The economics of a single bigger system can be more attractive than many small individual systems.