CHAPTER 3
APPLICATIONS OF A BIOMASS GASIFIER SYSTEM IN POWER GENERATION MODE: A FIELD STUDY

3.1 Historical background of the gasifier installation

In India Rice Mills are the typical medium scale industries and are scattered in various parts of the country. West Bengal is the main rice production state and many rice mills are situated in different districts, like Burdwan, Birbhum, Midnapore, Hooghly etc. The present case study is carried out in a mill situated at the village Tejgang, in the District of Burdwan, West Bengal.

Paddy is processed into rice through various processing technologies. The processing of rice mainly consists of cleaning, par boiling, drying, milling, polishing, separating and packaging. The processing of rice from paddy involves an energy intensive phenomenon. For these purpose rice mills are consuming both thermal and electrical energy. For processing of one kilogram of paddy into rice, the thermal demand is about 730 kcal and that of electrical demand is about 150 Wh. [1]. For running the boilers the thermal energy comes from burning of rice husk and electricity comes from the supply of West Bengal State Electricity Board (WBSEB) and the captive generation of the Mill by diesel generator is used for running machineries and other needs.

The direct combustion of rice husk under uncontrolled environment creates lot of pollutants leading to environmental hazards. Its combustion efficiency is also very low in the order of 10-12%. The cost of power from captive generation using diesel was profitable when diesel was cheaper. But, with the enhancement of diesel price captive generation becomes costlier and subsequently the added cost had the direct impact on the cost of rice produced. Moreover, the supply of electricity by local state agency (WBSEB) lacks in reliability and stabilized supply. Thus to overcome these problems and to sustain in the global market, it is necessary for the rice mills to have cost effective source of energy i.e., electricity [2]. Moreover, it saves foreign exchange by decreasing the need for imported oil. In the rice mills rice husk is a byproduct and immature paddy are the waste material. So the rice mills are the captive sources of these two items. The moisture content of rice husk and immature paddy and their calorific valve is suitable for
gasification to generate producer gas. So, gasification of these two items offers potential to generate electricity in a clean and efficient way. Therefore, this byproduct in the form of rice husk is treated as embedded power source of the rice mill.

3.2 Description of rice husk gasifier based power plant

A 350-kWe gasifier based power plant system has been installed at Maa Tara Modern Mini Rice Mill at Tejgang, Burdwan, West Bengal. The complete rice husk gasification based power system consists of following processes.

1. Feeding
2. Gasification
3. Ash removal
4. Heat recovery
5. Gas clean up
6. Water treatment
7. Power generation

The details of the above processes are briefly described in this section.

3.2.1 Feeding

The gasifier is fed by means of a bucket elevator to a screw conveyor and ultimately into the hopper, which is connected at the top of the gasifier. The bucket elevator is used to convey the biomass fuel from the storage pile to the hopper. The conveyors are completely enclosed. The biomass fuel is loaded from the feed hopper to the gasifier after a certain interval of time to match the gas consumption and to balance the requirement of the producer gas for dual fuel engine.

3.2.2 Reactor and gasification

In the rice mill the power plant is equipped with one 350-kWe rice husk based gasifier with a nominal gas production capacity of 600 Nm³/hr. The gasifier operates at negative pressure, which results from the suction of both the dual fuel engine and gas blower. It is an updraft, throat less and closed-top reactor. The gasifier body and the hopper are made up of mild steel. The gasifier has a higher reduction zone, which enables the gasifier to operate at lower temperatures with less tar entrainment in the produced gas. It was
designed for a heavy-duty cycle of 3600 hour per year operation. A high temperature resisting internal refractory lining is followed by cold face insulation liners at the exterior of the reaction zone.

The rice husk descends through the gasifier by means of gravity. At start-up charcoal is loaded below the hearth zone, with rice husk on top. Lighting is done with a torch. After start-up it only takes about five minutes for gas production to begin. This is because the charcoal reacts very quickly with air in the hearth zone. The total time of approximately 30 minutes is needed to attain the full gas production capacity. The air intake is provided by a system of pipes and nozzles. The preheating of the air is achieved by heat-exchange from the produced gas. Heat is conserved by insulating the outer casing. The gasifiers are designed to operate down to 25% of full load capacity.

If operation of the gasifiers is interrupted or terminated, the engines have to be turned off. But, if an appropriate temperature has already developed inside the gasifier, gasification re-starts immediately after turning on the suction blower, even after longer stop duration.

3.2.3 Ash removal

The ash content of the rice husk is comparatively higher than other types of biomass fuel particularly wood and the ash content of rice husk is approximately 14–15% by weight. The gasifier usually has a rotating grate with mechanical discharge from the base of the reactor. The grate is rotated from time to time by mechanical arrangements. The ash is taken out with shovel through a gas-tight service opening, sealed by water at the lowermost portion of the gasifier. This is done with two to three hours intervals when the temperature of the gasifier rose up to 600°C. Secondary and tertiary ash removal arises from cyclones, water washing systems and other gas filters.

3.2.4 Heat recovery

Heat may be recovered from the hot raw gas at several stages. The gas so produced will usually be hot, ranging from around 200°C to 300°C. It is needed to be cooled to increase the energy density. Washing by water is the first gas-cleaning step. This may provide the opportunity to recover heat as steam and can be reintroduced during gasification process. As a result up to 10% of the total energy content of the feed might be recovered. But such a process is yet to be implemented into the system. Care is taken to avoid tar deposition
or fouling of the heat exchanger surfaces with ash, char or any other contaminants. Further heat may be recovered but normally are of lower grade, although for larger plants, a more sophisticated water/steam cycle may be justified on a counter flow principle.

3.2.5 Gas clean-up

From the gasifiers the gas is first passed through a water-scrubber. It cools and filters the gas. As a result, the energy content in unit volume of gas increases. The water is led to pass through a high efficiency cyclone separator, which separates most of the tar and water. The water is recycled and again used for gas filtering and cooling. The amount separated has been on average 0.1% of the dry rice husk fed to the gasifier.

After the scrubber the gas is passed through another filter and a secondary charcoal filter. In the first filter tar deposits at the kinks, edges of the filter and separates from the gas. Whereas, in the charcoal filter the remaining dust and fly ash separates from the gas. The final impurities and moisture content of the gas is separated in a cotton bed filter located at the end of the gas conditioning system.

3.2.6 Water treatment

To clean and cool the raw syngas large quantity of fresh water is required. During wet washing and due to contamination of condensates from the process the water became contaminated and it is highly acidic, thus water treatment is imperative. In the centrifugal tar separator water is separated from the tarry water and recycled for filtering the syngas. When the condition of water attains a situation such that further cleaning becomes impossible to the desired level then it requires incineration or disposal. As it is highly acidic due to presence of phenols and related compounds and it is harmful for green vegetables, it is passed through alkaline ash deposited bed. As a result, its acidity is slightly reduced. It is believed that most organic compounds can be satisfactorily processed in conventional biological filters, so growth of water hyacinth in the stagnant pond can filter the wastewater.

3.2.7 Power generation

The clean and cool producer gas is ultimately fed to a dual fuel engine. An alternator is attached with the engine to generate power. The engine is designed in such a way that it
can run either in dual fuel mode or liquid fuel alone. At the beginning the engine starts by consuming diesel and later on feeding of producer gas through air inlet port reduces the diesel consumption. The engine-alternator set has following specification:

The Greaves D2 series is a 12 cylinder V-formed, water-cooled engines, with a cylinder volume of 0.1154 m³, bore/stroke diameter of 238/216 mm and a compression ratio of 10:1. The nominal power output of the engines running on diesel oil is 250 kVA at 1500 r.p.m. Specific fuel consumption under diesel operations is 63 lit/hr under full load (226.8 gm/kWh, Power rating 321 HP, Type and class of automatic governor – Class B-I, Mechanical, Starting system – 24 V battery operated. Gas/air mixers, control devices, etc. are the basic notable feature of the dual fuel engine.

Specification of alternator:

Speed – 1500 r.p.m., Voltage 415 V, frequency 50 Hz, Number of phase 3, Power factor 0.8, Type of enclosure – BS/IS (self screen protected), Type of duty – continuous, Type of insulation – as per BS/IS, Rating – 250 kVA, Voltage regulation – as per BS/IS.

3.3 Operation of the gasifier system

3.3.1 Operating procedures

Initially for the updraft gasifier, first the hopper, reactor and the combustion cone are decoupled. Then good quality charcoal pieces are filled above the grate based on the designed recommended quantity. The pit needs proper leveling. Then the hopper is set carefully without damaging the inner insulation. Care is taken to see that hopper is properly located and all bolts are tightened uniformly. The next step is to check water level in the manometers etc. Water is added if required and it is ensured that there are no blockages.

Dry and prepared biomass is then filled into the hopper above the charcoal level, up to the top of the hopper such that the feed door can be conveniently closed. The feed door is then locked.

An important part of the process is to check proper functioning of all motorized accessories such as blower, vibrator, grate and pump etc. Fresh fine filter material is then filled up to the indicated level. The fabric filter bag to be checked and replaced if required.
3.3.2 Starting procedure

To start the gasifier, the hopper is first filled with rice husk and the feed door is locked. The accumulated ash in the ash pond is removed and the water level in the pond is checked. Ash is also removed from the cyclone and such other accessories. The gas flare valve is opened and the gate valve, located in the gas line connecting to the engine, is closed. The diesel level, lubricating oil level etc. for the engine is checked. The air inlet valve is opened fully to make the gasifier ready for operation.

The diesel engine generator set is started normally as per its manual (on 100% diesel). Then the motor pump set is run and it is ensured that the pump starts delivering water through the cooling and cleaning sub-system. The vibrator as well as the blower is then started. Next the gasifier is fired using a torch through the air nozzles after removing the cap from the nozzle.

After about five to ten minutes of engine operation on 100% diesel, the gas can be fed to the engine by fully opening the gas valve and partially closing the air intake valve. At this point, the flare valve should be fully closed. The air intake valve is then adjusted for maximum diesel replacement. This can be achieved by progressively closing this valve until engine emits black smoke and leading to improper combustion. While the gas is being fed into the engine, the Governor Control Knob is adjusted to maintain the frequency at 50 Hz (±1%).

3.3.3 Running procedure

On-line feeding of rice husk in the gasifier is required at regular intervals of about 1 and ½ hours, observing proper safety. It is to be followed strictly to avoid inconsistent gas production and damage to the gasifier. Due to the uniform size of the rice husk and low moisture content (less than 20%); there is no problem during gasification process. But, care should be taken so that the pressure does not exceed the pull beyond maximum on the PN (Pressure on Nozzle) & PG (Pressure of Gasifier) valves.

In case of dual-fuel mode it is ensured that flare valve is fully closed when the engine is running. Filter media should be changed every 48 hours of operation. PFF (Pressure of Fine Filter) should be maintained between the ranges. It is necessary to observe hourly rate of rice husk consumption, at different loads.
3.3.4 Shut down sequence

During shut down the gasifier, flare valve is to be opened first, followed by the opening of the gas valve. Then the gas blower, vibrator & combustor are to be switched off. Caps are required to be used to plug all the air nozzles tightly. The scrubber pump is then allowed to run for approximately 5 minutes after that it is switched off. The flare valve is then closed completely, followed by the closing of probe cocks of PN & PG and manometer tube links with these cocks are removed. The engine is reverted to 100% diesel mode by opening the air intake valve fully and closing the gas valve. It is to be run for a few minutes on diesel and then shut down.

3.4 Operational experiences

The 350-kWe-updraft gasifier system has been supplied by Grain Processing Industries Pvt. (I) Ltd., Kolkata, West Bengal. The gasifier was operated using rice husk. Immature paddies are also used as a feeding material along with rice husk. The thermal output in terms of the heating value of producer gas was in the range of 900-1200 kCal/Nm³.

3.4.1 Fuel characteristics

The fuel properties for gasification purposes were successfully tested on rice husk and immature paddy. Table 3.1 gives the proximate and ultimate analysis of these two types of fuels, and Table 3.2 shows analysis of ash of these two types of biomass.

From the two tables it is observed that immature paddy contains more amount of volatile matter and carbon compared to rice husk and has the lowest contents of ash particularly silica component. It is also found that the ash of immature paddy contains more alkalis than the ash of rice husk.

From proximate analysis it is observed that immature paddy has a relatively high volatile matter (59.3%), high fixed carbon (14.9%), high ash content (13.3%) and high silica content (91.24%) of the ash. Its uniformity of particle size and low moisture content (12.5%) is very beneficial for gasification purpose. Addition of immature paddy also acts as temperature moderator and helps in maintaining constant temperature during gasification process. Experimental results also support this idea. Moreover, the calorific value of immature paddy is higher than rice husk.
Table 3.1: Proximate and ultimate analysis of rice husk and immature paddy
(air-dry basis)

<table>
<thead>
<tr>
<th></th>
<th>Immature paddy (%)</th>
<th>Rice husk (%)</th>
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</thead>
<tbody>
<tr>
<td><strong>Proximate analysis</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volatile matter</td>
<td>59.30</td>
<td>47.10</td>
</tr>
<tr>
<td>Fixed carbon</td>
<td>14.90</td>
<td>14.70</td>
</tr>
<tr>
<td>Ash</td>
<td>13.30</td>
<td>28.00</td>
</tr>
<tr>
<td>Moisture</td>
<td>12.50</td>
<td>10.20</td>
</tr>
<tr>
<td><strong>Ultimate analysis</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon</td>
<td>58.00</td>
<td>48.88</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>3.60</td>
<td>3.80</td>
</tr>
<tr>
<td>Sulfur</td>
<td>0.34</td>
<td>0.20</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>0.90</td>
<td>0.81</td>
</tr>
<tr>
<td>Oxygen</td>
<td>21.51</td>
<td>15.13</td>
</tr>
<tr>
<td>Calorific value (kcal/kg)</td>
<td>4454</td>
<td>4200</td>
</tr>
</tbody>
</table>

Table 3.2: Comparison between ash of immature paddy and ash of rice husk

<table>
<thead>
<tr>
<th></th>
<th>Ash of immature paddy (%)</th>
<th>Ash of rice husk (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silica as SiO₂</td>
<td>91.24</td>
<td>95.11</td>
</tr>
<tr>
<td>Alumina as Al₂O₃</td>
<td>0.88</td>
<td>1.50</td>
</tr>
<tr>
<td>Iron Oxide as Fe₂O₃</td>
<td>0.36</td>
<td>0.54</td>
</tr>
<tr>
<td>Calcium as CaO</td>
<td>1.39</td>
<td>1.80</td>
</tr>
<tr>
<td>Magnesium as MgO</td>
<td>1.75</td>
<td>0.10</td>
</tr>
<tr>
<td>Alkalies etc.</td>
<td>4.38</td>
<td>0.95</td>
</tr>
</tbody>
</table>
3.4.2 Gasifier system performance

The gasification system was extensively tested on the fuels listed above in the field as well as in the laboratory. A synopsis of the data is given in Table 3.3.

Table 3.3: Gasifier performance data during field testing

1. Number of hours of operation per day: 10 hr (average)
2. Fuel consumption: 250-300 kg/hr (air-dry basis)
3. Gas characteristics
   (i) Gas output: 1.5-1.7 Nm\(^3\)/kg of rice husk (15% moisture)
   (ii) Flow rate: 425-510 Nm\(^3\)/hr
   (iii) Higher heating value: 900-1100 kcal/Nm\(^3\)
4. Char characteristics
   (i) Amount generated: 147-177 kg/hr
   (ii) Higher heating value: 2200 kcal/kg
   (iii) Ash content: 70-84 kg/hr
5. Process parameters
   (i) Gas outlet temperature from gasifier: 200-300\(^0\)C
   (ii) Gas temperature at engine inlet: 40-50\(^0\)C
6. Gasifier performance (MJ/h)
   (i) Total thermal input: 4410-5290
   (ii) Energy content of gas: 1963-2356
   (iii) Energy content of char: 1353-1630
7. Engine performance
   (i) Power output: 250 kW
   (ii) Gas inlet temperature: 40-50\(^0\)C
   (iii) Gas outlet temperature: 60-70\(^0\)C
It is evident from Table 3.3 that the gasifier was operated at only 250 kWe (maximum) whereas the rated capacity of the system is 350 kWe. The biomass consumption rate during power generation normally varied between 250-300 kg/hr (dry), depending on the loading. At full load condition, the biomass consumption was 300 kg/hr (dry), whereas the corresponding low loading consumption was 250 kg/hr.

### 3.4.3 Problem arises during gasification

It is observed that when the gasification temperature is more than 850°C the quality of the producer gas is poor and it is also true for an operating temperature bellow 700°C. To know the exact reason, SEM analysis was carried out of the ash and/or unburnt carbon that remains after gasification of rice husk and mixture of rice husk and immature paddy in different percentage at various temperatures. It is observed from SEM photograph (Figure 3.1) of rice husk ash that some liquid phase fused onto the surface of the char particles and forming a glass like barrier when the gasification temperature is more than 850°C. As a result it prevents the reaming char to come in contact with oxygen for further reaction. At a lower temperature below 700°C a large part of carbon in the fuels remains unburnt, which is confirmed from the SEM photograph (Figure 3.2). From the XRD analysis (Figure 3.3) it is confirmed that after gasification at 900°C the surface of husk is converted into $K_6Si_2O_7$, $Al_2(SiO_4)O$ and $Ca_2(SiO_4)$. At higher temperature silica, potassium oxide and aluminium oxide, which are present in the ash fused and forms a liquid phase that coated the unburnt carbon. From XRD analysis (Figure 3.4) it is seen that the intensity of the peaks reduces due to addition of immature paddy, which indicates reduction of silicate formation during gasification at 900°C. As a result the gasification efficiency is lower and at this temperature tar content of the gas is excessive. It is observed that better reaction between carbon and oxygen is taking place at a temperature range of 700–850°C and at this temperature range the system operated smoothly. Decreasing the air feed and increasing the rice husk feed rate can reduce this higher temperature, whereas, low temperature requires the opposite strategy. In addition to this it is also observed that addition of immature paddy along with rice husk at that particular temperature gives good quality gas and also helps to maintain constant temperature to complete gasification reactions and it also acts as a temperature moderator for gasification of rice husk.
Fig 3.1: SEM photograph of rice husk ash, collected after gasification at 900°C.

Fig 3.2: SEM photograph of rice husk ash, collected after gasification at 600°C.

Figure 3.3: XRD of rice husk ash, collected after gasification at 900°C.

Figure 3.4: XRD of mixture of rice husk and immature paddy (1:1) ash, collected after gasification at 900°C.
3.4.4 Problem arises during power generation

The plant operated with a dual fuel diesel engine of 250-kVA rating for power generation. After installation and test running of the updraft gasifiers, some problem arises due to the presence of tar in the scrubbers, filters and this causes operational abnormality in the engine. Very high temperature zones in the gasifiers were also registered. These abnormalities or difficulties were observed during field operation.

During power generation from producer gas by dual fuel engine a black compound is deposited on the cooler, radiator and different parts of the engine. After six months of operation it started to peel off and affects the piston and imposed serious problems to the engine. An unacceptable level of maintenance is incurred which cause fouling of the engine. The gasifier system was then shut down for cleaning and the pipes and equipment are cleaned thus it can be reused for gasifier operation again. Physical and chemical analyses of the black compound were conducted and it is confirmed that the above black coating is sulfide material (Figure 3.5).

![Figure 3.5: XRD analysis of the deposited compound.](image)

A chromatographic analysis of the collected compound from the after cooler of the engine has been done. The chromatogram of the sample is given in Figure 3.6. The analysis proves that some hydrocarbons viz. C_{22}, C_{23}, C_{26} etc are present in the
compound. The deposited compound is formed due to the reaction between the hot gas, which contains some tar and copper plates of the after cooler.

![Chromatogram of the compound containing tar.](image)

Figure 3.6: Chromatogram of the compound containing tar.

Atomic absorption spectroscopic analysis of the deposited compound was also carried out. It is observed that it contains some elements, which is depicted in the following table. So it is confirmed from the above discussion that a certain amount of tar and particulates are still present in after cooling & filtering of the producer gas.

Table 3.4: Atomic absorption spectroscopic analysis of the deposited compound

<table>
<thead>
<tr>
<th>Element</th>
<th>mg/lit (200 mg sample in 100 ml solution)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ca</td>
<td>0.353</td>
</tr>
<tr>
<td>Fe</td>
<td>3.533</td>
</tr>
<tr>
<td>K</td>
<td>0.557</td>
</tr>
<tr>
<td>Mg</td>
<td>1.2</td>
</tr>
<tr>
<td>Mn</td>
<td>0.035</td>
</tr>
<tr>
<td>Na</td>
<td>2.734</td>
</tr>
<tr>
<td>Ni</td>
<td>2.914</td>
</tr>
<tr>
<td>Zn</td>
<td>0.332</td>
</tr>
<tr>
<td>Cu</td>
<td>424.9</td>
</tr>
</tbody>
</table>
Chemical analysis of the deposited sample confirms that the sample also contains sulfur. It is confirmed by the following reaction.

\[
\text{Heat + Zn dust} \quad \text{Sample + 1:1 H}_2\text{SO}_4 \quad \text{Smell of H}_2\text{S}
\]

The reasons for this were expected to lie in the fact that during filtering and cooling of the producer gas, before it is fed to the dual fuel engine it is passed through a fuel filter activated by diesel oil. This results in contamination of the sulfur in the gas stream. As a result this sulfur reacts with the copper plate of the radiator, after-cooler and other parts of the engine and formed a coating of black compound of Cu$_2$S that ultimately corrode those parts of the engine. Now the problem is overcome by changing the material by stainless steel instead of copper and the diesel filter is also removed.

The tar content of the immature paddy was remarkably high. So to solve the above mentioned problems an extra secondary charcoal filter was taken into use.

The plant operational data is evaluated for providing information for system component and also re-engineering of the system. More efficient washing and cleaning system have now replaced the soap bubbling filters, which are rather maintenance intensive and problematic. For round the clock operation these filters can be provided to carry out maintenance without stopping the gasifier.

Thus, a major source of downtime in most gasification systems, namely that of choking of pipes/equipment with tars and particulate matter, appeared to be successfully tackled by employing a hot gas cleaning system.

Tests with different moisture contents of the fuel indicated that excellent performance was possible if the moisture content was less than 15% (wet basis). A pilot flame to sustain gas combustion was found to be necessary for moisture levels between 20-25%. However, combustible gas was not formed at all if the moisture content exceeded 25% (wet basis).

### 3.4.5 Diesel replacement

In the Rice Mill, the gasification system is coupled with a 250-kWe dual fuel engine for power generation. Under full load condition the unit consumed 54 litters of diesel per hour. The diesel replacement was maximized up to 70% when only rice husk is used for
gasification. However, it is observed that a mixture of rice husk and immature paddy at a weight ratio of 1:1 generate good calorific value producer gas, which can even replace diesel up to 80-85% because the net calorific value of rice husk is 4200 kcal/kg whereas for immature paddy it is 4454 kcal/kg. A comparative study on diesel replacement for the 250-kWe gasifier systems is presented below.

![Variation of diesel replacement in dual fuel engine with time: Gasification from rice husk with and without immature paddy.](image)

Figure 3.7: Variation of diesel replacement in dual fuel engine with time: Gasification from rice husk with and without immature paddy.

From the figure it is clear that approximately 40 minutes time is needed to achieve full gas production capacity and to stabilize the system.

### 3.5 Profitability of using producer gas

The generation of electricity with producer gas by gasifying rice husk at the rice mill has turned out to be a successful and profitable operation due to its diesel replacement capability, compared to the alternative way of using only diesel oil as a fuel. Indian rice mills are using both conventional electricity as well as electricity from captive diesel generator. Production of 1-kWh electricity consumes 1-1.2 kg of rice husk, while the consumption of diesel oil is 0.1 lit. With the hike in diesel price captive generation is not viable for mills with respect to the selling price of the rice. Thus the mills are facing problems with the conventional diesel generators. Moreover, for quality processing the mills require quality power which is not available from the mill owner. So it is a very
favorable option for generating power using a dual fuel engine in the rice mills. The economic viability is determined from the following results.

Table 3.5: Electricity production cost using gasifier–dual fuel generator combination

1. Capital investment (including equipment & installation)  US$ 1,14,077
2. Biomass consumption (@ 1-kg/kWh)  350 kg/hr
3. Diesel consumption (for 70% / 80% replacement)  22.8/15.2 lit/hr
4. Operating worker  2 Persons
5. Maintenance / spare parts (assuming 1% of capital cost / year)  US$ 1140.77
6. Operation period of mills:
   (120 days for 15 hours a day and 180 days for 10 hours a day)  3600 hours
7. *Lifetime of the gasifier*  10 years
   (i) Gas production system capital cost  US$ 0.0091
   (ii) Biomass fuel charge
      a. Fuel wood @ US$ 0.034/kg  US$ 0.034
      b. Husk @ US$ 0.021/kg  US$ 0.021
      c. Husk + immature paddy  US$ 0.010
   (iii) Diesel fuel charge (US$ 0.66/lit)
      a. In case of 70% replacement  US$ 0.043
      b. In case of 80% replacement  US$ 0.029
   (iv) Operating charge  @ US$ 45.63 / Month  US$ 0.0009
   (v) Maintenance  US$ 0.0009
8. Cost of electricity generation (using 50% capacity utilization factor)
   a. Using fuel wood & diesel  US$ 0.088/kWh
   b. Using husk & diesel  US$ 0.074/kWh
   c. Using husk + immature paddy & diesel  US$ 0.049/kWh
At the present moment husk is burnt in conventional oven and the conversion efficiency is very low, in the order of 8-10% and it creates many problems like partial combustion and emission of particulates.

Moreover, by selling biomass generated tar there are also some profits of the rice mill.

The economic attractiveness and benefits of applying the technology are very sensitive to the price of diesel oil, load capacity, total annual operating hours and the level of diesel oil substitution. The above studies indicated that powering the rice mill with rice husk gasification is an appropriate solution and very much attractive proposition to the rice mills. As the input materials i.e., rice husk and immature paddy grains are produced from the rice mills as the by product thus this is really an embedded source of fuel for power generation to the rice mills.

3.6 Conclusion

The present study clearly demonstrated that low-density agricultural waste based gasifier running on rice husk and immature paddy can be successfully retrofitted to existing diesel engine in the rice mills and oil-fired furnace/boilers in metallurgical and other industries. The economics of the system is also very much attractive. At higher capacities, the economics will be even more favorable for the gasification systems. The other positive socio-economic impacts of using agricultural waste based power generation are difficult to express in numbers but are obvious.
References
