Chapter 2

Biomass gasification plant in the state of

West Bengal, India: A field study
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2.1 Introduction

Energy is the very basis of life; insufficiency of which brings economic stagnation by lowering optimum productivity. Energy sufficiency or energy security, therefore, is the most talked about topic everywhere, starting from each and every street and lane to the country’s highest institution - The Parliament - and among the academicians, intellectuals, bureaucrats, executives and politicians. There is no denying the fact that access to a steady supply of sufficient and clean energy is critical for holistic development, irrespective of their social and/or economic status and geographic location. In order to have an effective approach in addressing these issues, there is a solution for energy security through the use of local resources. The common locally available resources in India are solar energy and biomass energy. In these rural areas, more than 80% of the people are involved in the agricultural activities, as agriculture is the backbone of the economy. Agricultural wastes are mainly used for two purposes (1) Cattle feedstock (2) Fuel. However, burning of these fuel causes severe problem as these biomass fuels are burnt in conventional ovens and the persons operating the ovens are exposed to smoke and particulate matter (PM). Inhaling of these has severe impact on the health which includes early cataract, lung problem and Anemia. As the women are mainly involved in cooking food by using biomass fuel, they are mostly vulnerable to these diseases. Anemia has severe impact on women health and apart from the issue of their own weakness; they also give birth to disabled child. This is a major problem for using of biomass fuel with low efficiency methodologies.
For lighting purposes and running of agricultural gadgets like the agricultural pumps and
tillers, kerosene and diesel are used in the rural areas. As many of the villages have either no
access to electricity or an access to unreliable electricity, so, the mentioned agricultural gadgets
are run either by kerosene or by diesel or using the mixture of both. Supply of these fuels has two
major problems of availability and affordability. The availability depends upon the supply from
the main source. If there is any problem in the supply of these fuels, then the farmers face
problem. Similarly, owing to the occurring of some unwanted events like general strike,
casualties etc., the price of the reserved fuel rise. Consequently, the people of the rural areas face
problem in affording the price of the fuel. To overcome these problems, there is a crying need to
substitute the conventional fuel through the use of local resources like solar, wind and biomass.
However, wind is very erratic but, the solar and biomass energies are quite dependable. So,
integration of the two things can bring energy security in the rural areas. In this chapter, an
experimental analysis will be discussed on the extraction of energy from the biomass resources
[14, 19]. Traditionally, biomass is burned in kilns or furnaces. Efficiency of these furnaces are
quite low in the range of 8-12% and their burning, it has been observed that lots of unburnt
particulate matters come out which are called black carbon or soot. And this soot has bad impact
both on health and on the climate change, as evident from The Indian Ocean Experiment
(INDOEX, 2001). Thus special attention is being given to enhancing the efficiency of burning
biomass and to reduce the particulate emission. For this purpose, an experiment has been
conducted to study in enhancing the efficiency of extracting effective energy from the biomass.
Detail of the experiment has been discussed in the chapter and its industrial use has also been
mentioned here.
Burning of biomass is an exothermic reaction and the heat is used for several applications. But if the biomass is set in the destructive distillation process, then two components are obtained i.e. Synthetic fuel which is a mixture of Carbon Monoxide (CO), Hydrogen (H₂) and a small amount of Methane (CH₄) which is a fuel gas and a liquid component which contain bio-oil which can be refined and then be blended with conventional diesel fuel. To synthesize the products, a small experiment was conducted at the laboratory scale and its various aspects were analysed. The destructive distillation process was conducted in a chamber where biomass was treated under thermo-chemical reactions in the presence of very low amount of oxygen [33, 50, 51]. In this process, biomass undergoes four distinct steps which are Drying, Pyrolysis, Oxidation and Reduction.

After these four steps, synthetic fuel gas is extracted which can be used to replace the conventional fuel. This process was adapted in large scale by many industries to conserve the diesel fuel. In rural areas, this technique was coupled with the diesel engine to conserve diesel fuel to generate electricity.

2.2 Field Study on the Set up of Biomass Downdraft Gasifier

Gasifier has been visited at Pancha Shimul, Burdwan district, West Bengal, India. This is a device where the raw biomass is processed under thermo-chemical reaction to have combustible fuel gas. So, gasifier is a closed chamber, as shown in figure 2.1, where the raw biomass is put and processed it to have the synthetic fuel gas or syngas. Initially in the gasifier, a charcoal bed was kept and the bed was fired in presence of very low amount of oxygen or air. When the appropriate temperature reaches, the input biomass was introduced into the processed chamber to go for thermo-chemical reaction. In the thermo-chemical reaction, four stages of reaction take place and these are drying, pyrolysis, oxidation and reduction. In these four
processes and in the presence of low quantity of oxygen, syngas also known as producer gas is produced inside the chamber and the gas is extracted from the chamber.

When biomass undergoes thermo-chemical reaction, it produces not only the syngas but also other substances like phenolic acid (commonly known as tar), particulates and other gases. The gases, except syngas, are harmful for human health as well as for the mechanical engine, unless special care has been taken to filtrate the syngas, using the filters as shown in figure 2.2 and 2.3, from the mentioned gases and particulates.
In rice husk gasification, the rice husk was put down in the rice husk chamber and after a particular time, the gas starts getting produced. The produced gas was passed through a venturi scrubber and taken out of the chamber. The venturi scrubber has 2 functions. In the 1st case, it cools the gas and in the 2nd case, it removes the phenolic acid and the particulates partially. But the major contribution of the venturi scrubber is to evacuate the gas from the system to the burning point. After venturi scrubber, the gas is passed through a couple of superfine filtering arrangement. This arrangement contains moisture absorbing element and trapping of finer particulates. So, clean and cool gas finally fits to the carburetor of the engine with a particular proportion of diesel gas, air and synthetic gas. The optimum condition of the gas mixture burn in
an engine, as shown in figure 2.4, and helps the engine to run smoothly with low diesel consumption.

2.3 Mathematical Analysis

Unit generation cost has been calculated in the following section for two cases. In the first case, the whole system with only diesel generator has been considered and in the second case, introduction of syngas produced from the biomass downdraft gasifier has been added. The formula to be used in the sample calculation is:

\[
\text{Unit generation cost (INR/kWh)} = \frac{(\text{Capital cost} \times \text{ROI}) + (\text{Fuel cost} \times \text{hours of operation}) + \text{Overhead cost}}{\text{Number of Units generated}}
\]  

(2.1)

where, ROI= Rate of Interest

Number of units generated = (kVA rating \times Power factor \times Load \times No. of operating hours)  \quad (2.2)

2.4 Sample Calculation

Following are the cost analysis and carbon dioxide savings of this system studied in field study at Pancha Shimul, district Burdwan, West Bengal.

2.4.1 Cost Analysis

A 200 kW gasifier was designed for this purpose and installed in rice mills to be coupled with a 250 KVA diesel generator. As per the recorded data, the diesel generator consumed at the initial stage 54 liters of diesel per hour. Using equation 2.2,

Now using (2.1), the unit generation cost of diesel has been calculated.

Unit generation cost

\[
\frac{(\text{Capital cost} \times \text{ROI}) + (\text{Fuel cost} \times \text{hours of operation}) + \text{Overhead cost}}{\text{Number of Units generated}}
\]
\[
\Rightarrow \text{Unit generation cost for diesel (INR/kWh)} = \frac{((12,00,000 \times 12\%) / 365) + (56.26 \times 54 \times 15) + 500}{2400}
\]

So, unit generation cost for diesel = Rs 19.36

After using gasifier, it has been practically observed that diesel consumption gets reduced by 70% i.e. the diesel consumption comes down from 54 liters to 16.2 liters. Using (2.2),

\[
\text{Unit generation cost for diesel after using gasifier} = \frac{((12,00,000 \times 12\%) / 365) + (56.26 \times 16.2 \times 15) + 500}{2400}
\]

So, unit generation cost for diesel after using gasifier = Rs 6.069

\[
\text{Unit generation cost for syngas} = \frac{((16,00,000 \times 12\%) / 365) + (1.6 \times 250 \times 15) + 500}{2400}
\]

So, unit generation cost for diesel after using syngas = Rs 2.975

Thus, the total fuel cost per day after the use of syngas = Rs 9.044

Here, it is clearly marked that the difference in the unit generation between both the procedures is Rs. 10.316.

2.4.1. **Carbon credit earnings**

Burning of 1 liter of diesel generate = 2.62 kg of CO₂.

CO₂ produced before introduction of syngas = 2.62 \times 810 liters per day = 2122.2 kg CO₂ per day.

CO₂ produced after introduction of syngas = 2.62 \times 243 liters per day = 636.66 kg CO₂ per day.

Total savings = (2122.2 - 636.66) = 1485.54 kg of CO₂ per day.
Table 2.1. Comparison of cost and carbon dioxide savings

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Initial cost (in rupees)</th>
<th>Rate of Interest</th>
<th>Unit Fuel cost (in rupees)</th>
<th>Operating hours per day</th>
<th>Fuel used per hour</th>
<th>Overhead cost (in rupees)</th>
<th>Units generated (from equation 2.2)</th>
<th>Cost</th>
<th>Financial benefit per unit</th>
<th>Percentage saving</th>
<th>CO₂ Produced per day (in kg)</th>
<th>CO₂ saved per day (in kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CASE I</td>
<td>Diesel Engine</td>
<td>1200000</td>
<td>12% p.a.</td>
<td>53</td>
<td>15</td>
<td>54 liters</td>
<td>500</td>
<td>2400</td>
<td>19.36</td>
<td>0</td>
<td>0</td>
<td>2122.2</td>
</tr>
<tr>
<td>CASE II</td>
<td>Diesel engine</td>
<td>1200000</td>
<td>12% p.a.</td>
<td>53</td>
<td>15</td>
<td>16.2 liters</td>
<td>500</td>
<td>2400</td>
<td>6.069</td>
<td>10.316</td>
<td>53.28%</td>
<td>636.66</td>
</tr>
<tr>
<td>Syngas from gasifier</td>
<td>1600000</td>
<td>12% p.a.</td>
<td>1.6</td>
<td>15</td>
<td>15</td>
<td>250kg</td>
<td>500</td>
<td>2400</td>
<td>9.044</td>
<td>Carbon neutral</td>
<td>Carbon neutral</td>
<td></td>
</tr>
</tbody>
</table>

Table 2.1 shows the environmental and economic benefits of using syngas in a dual-fuel engine.

Since syngas is carbon neutral, the environmental benefit includes a reduction in 1485.54kg of CO₂ emission to the atmosphere. Cost reduction of Rs10.316 is noticed from the calculations in table 2.1.

### 2.5. Product and Byproduct of Gasification Process

Gasification process involved heating of rice husk to a high temperature. As a result, volatile compounds (gases) and solid residues (char) were produced. The volatile compounds vary in their composition and quantity according to the reactor temperature and type, the characteristics of the fuel and the degree to which various chemical reactions occur within the process [58, 62, 69]. Primary reactions in the presence of oxygen produce carbon monoxide (CO) and carbon dioxide (CO₂). It is in this phase of reactions that high amount of heat is released, resulting in producing the energy that is needed to sustain other reactions of gasification. The product obtained in this downdraft gasifier is syngas and the byproducts are tar and char.
2.5.1. Syngas

It is a mixture of carbon monoxide (CO) and hydrogen (H₂), produced from high temperature oxygen gasification of rice husk. Once this syngas is cleaned using the ash filter, dry scrubbers and fabric filter already incorporated in the system, impurities such as tar can be removed. This purified syngas is then fed to the dual fuel generator. Syngas can also be helpful in producing liquid biofuels e.g. synthetic diesel (via Fischer-Tropsch synthesis) or organic molecules e.g. synthetic natural gas (SNG-methane (CH₄)). The dual fuel generator is operated under the Diesel cycle, which is a closed cycle commonly used to study the cylinders of spark-ignition, internal combustion, automobile engines, i.e. gasoline engines. Diesel cycle is a compression-ignition cycle and, therefore, do not require a separate energy source (e.g. from a spark plug) to burn. Diesel Cycles have four stages – Compression, Combustion, Expansion, and Exhaust.

Compression – The syngas is compressed by moving the piston up the cylinder. It is in this part of the cycle that work is contributed. In the ideal Diesel cycle, this compression is considered to be isentropic. Pressure and temperature increases, whereas volume decreases. Entropy remains constant.

Combustion – Diesel fuel is introduced in this phase. Heat gets added by fuel combustion at constant volume. The heat addition is isochoric.

Expansion – Fuel is burned to heat the compressed air and the hot gas expands forcing the piston to travel down in the cylinder. It is in this phase that the cycle contributes its useful work, rotating the automobile's crankshaft. Isentropic condition is marked.
2.5.2. Tar

The tar obtained in the process, as seen in the case study, is thrown away. However, it has significant uses after its cooling and cleaning. The tar can be utilized to result in bio-oil whose blended form with diesel oil can again be fed to the dual fuel generator. This will lead to the reduction of further consumption of diesel in the dual fuel generator. Initially, the 200 kW generator was consuming 54 liters of diesel per hour. This reduced to 16.2 liters per hour, after the introduction of syngas through the gasification system. This diesel consumption can potentially be further reduced if the tar obtained from this process is again used in this process, after its purification.

2.5.3. Char

Complete combustion requires about 4.58 pounds of air in 1 pound of bone-dry biomass which holds 0% moisture. This is referred to as the stoichiometric air. In the gasification reactions, since it is the partial combustion, hence, a fraction of the stoichiometric air is provided, which is referred to as an equivalence ratio (ER). With dry biomass, ERs of a range of 0.20 to 0.33 is provided, which implies that, for normal gasification, about 1.15 pounds of air is required for 1.0 pound of biomass [69, 71, 75].

After the completion of this gasification process, the next byproduct is char. Char has potential applications. The author of [55] describes the utilization of char as a catalyst for tar decomposition. This tar is usually decomposed catalytically or thermally. Tar contains well dispersed catalytic minerals and metals on its surface and also owns a surface area higher than many catalysts. The prime concerns of using catalysts for the decomposition of tar are (a) cost.
(b) Deactivation. Both of these issues can be ruled out using char as (a) it is a byproduct of the gasification process and hence there is no need to purchase expensive catalysts (b) The deactivated char could be easily replaced by fresh char which is produced inside the gasifier [55].

2.6. Recommendations for Innovation in Gasification Process and Technology

The syngas contains a variety of contaminants produced from impurities present in the feed material that is gasified using the downdraft biomass gasifier. Syngas produced from biomass contains acid gases including HCl, HCN, and H$_2$S. It also contains NH$_3$ and CO$_2$. All of these components must be removed to avoid poisoning of catalysts used in downstream upgrading processes. Physical absorption methods are effective means to remove CO$_2$ and H$_2$S from syngas. The choice depends on the availability and/or cost of process steam compared to refrigeration. These systems are parasitic in nature, and comprise the bulk of the cost associated with syngas cleanup. The high CO$_2$ content of syngas produced from biomass further increases the demand on these systems. Syngas produced from biomass also contains significant amounts of tar and soot. Syngas from these systems also contains considerable amounts of light hydrocarbons, including aromatic species. The aromatic components must be removed to prevent poisoning of downstream adsorbents in guard beds used to protect catalysts in the upgrading processes. Hence, the syngas produced from the gasification of rice husk using downdraft gasifier is passed through the following steps:

(a) Cyclone helps in water-cooling. Here, the gas is cooled and partial cleaning is also achieved.

(b) Ash filter – 1 ash filter has been used. This removes carbon and ash based residues.

(c) Scrubbers – 3 scrubbers have been used here. Moisture from the syngas is removed using this.

(d) 1 fabric filter at the end of the process is used. The gas passes through the filtration unit consisting cloth. This cleans up the gas completely.
Here, the addition of another cyclone is possible. This will further clean the gas, prior to its movement towards the ash filter. A closed dedicated extraction cycle can be utilized to prevent the emissions of charcoal dusts. Electrostatic filter can be used which will efficiently remove dust and condensable tar droplets from product gas. A gas residence time of 4 seconds is enough for total tar removal. The internal of the Electrostatic Precipitator (ESP) is not polluted. The cleaned product gas fires a gas engine. Investment costs for ESP with a capacity of 10 MW\textsubscript{th} is nearly 15 €/kW\textsubscript{th}. Hence use of ESP can be a very attractive solution for combined tar aerosol and dust removal. Cyclone, ceramic filter, fabric filters, granular bed filters, and dry and wet electrostatic precipitators are generally used for particulate removal and tar removal. The particles and tar produced during the gasification process should be removed simultaneously in scrubbers. The operating temperature of fabric filter is between 60-250°C and so, it may not be practical for this purpose in the initial stages of purification. Dry electrostatic precipitators may condense the heavy fractions of tar and significant carbon content. This results in increase of electric conduction, and reduction of dust removal efficiency. Hence only using ESPs may not be a preferred option for biomass syngas cleaning.

Therefore, a combination of cyclones with either ceramic or granular (sand) bed filters is preferred for high and medium temperature gas cleaning. But the mechanical strength of ceramic filters is not enough and also is accompanied by low thermal conductivity [75, 79, 80, 82, 83]. According to Yang Gua-Hua and Zhou Jiang-Hua (2007), the dust collection capacity of dual layer granular bed filters with bed particle sizes of 0.7 mm and 3 mm is high. Hence, cyclone combined with dual layer granular bed filter, which is cheaper and has more flexibility for partly sticking particles, is a good option [62]. A temperature less than 600-650°C is usually preferred for removal of alkali vapour with the dust particles.
Table 2.2. Different types of filters

<table>
<thead>
<tr>
<th>Dust separator</th>
<th>Temperature Range (°C)</th>
<th>De-dusting efficiency</th>
<th>Pressure drop (Kpa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cyclone</td>
<td>100-900</td>
<td>Dust&gt;5µm, 80%</td>
<td>&lt;10</td>
</tr>
<tr>
<td>Fabric bag filters</td>
<td>60-250</td>
<td>Dust&gt;0.3µm, 99 - 99.8%</td>
<td>1-2.5</td>
</tr>
<tr>
<td>Wet scrubbers (venture)</td>
<td>20-100</td>
<td>Dust 0.1-1µm, 85 - 95%, otherwise 90 - 99%</td>
<td>5-20</td>
</tr>
<tr>
<td>Fibrous ceramic filters</td>
<td>200-800</td>
<td>Dust&gt;0.3µm, 99 - 99.8%</td>
<td>1-2.5</td>
</tr>
<tr>
<td>Rigid ceramic filters</td>
<td>200-800</td>
<td>Dust&gt;0.1µm, 99.5 - 99.99%</td>
<td>1-5</td>
</tr>
<tr>
<td>Metallic foam filters</td>
<td>200-800</td>
<td>Dust&gt;1µm, 99 - 99.5%</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Granular Bed filters</td>
<td>200-800</td>
<td>Highly depends on regime and surface cake filtration</td>
<td>&lt;10</td>
</tr>
</tbody>
</table>

Table 2.2 provides the different types of filters with their parameters, which can be used in the gasification unit.

2.7. **Novel method for extraction of liquid fuel from biomass feedstock**

From the case study of downdraft biomass gasifier, tar was obtained as a byproduct. In order to examine its applicability, a laboratory scale experiment was conducted. In this experiment, rice husk as a feedstock having 11.15% moisture content was introduced to a fixed bed reactor. This reactor is a tube furnace having a stainless steel tube inside it. A rotary vacuum pump was connected to the tube furnace and was switched on. As soon as the air leaving rate at the exhaust point of the pump becomes negligible, the fixed bed reactor was turned on, as maximum of the air or gases has been pulled out from the confined area, making the area vacuum. This helped the rice husk that was fed to the tube furnace, to be heated up in a controlled atmosphere. So, the rice husk was kept inside the tube and temperature was set at 300°C. This experiment was conducted at a heating rate of around 12°C per minute. The temperature was gradually increased till 700°C.
Soon after 300°C, the thermo-chemical process of the rice husk got initialized. This is the phase of pyrolysis. Gaseous matter got generated. A pipe was connected from the tube furnace to a spiral tube water cooled condenser. This gas got condensed and fine droplets were collected at a liquid receiver kept under the spiral tube water cooled condenser. This is the pyrolysed oil, which was obtained along with gas and ash. The ash was left untouched for around 24 hours and then taken out of the tube furnace, while the gas produced during the process was fed into the atmosphere. Details of the rice husk gasification, methodology of coupling with the engine and impact to ecology, economy and empowerment to be discussed in the text of this chapter given below.

**System Specifications**

The experimental set up consists of a fixed bed reactor, a water cooled condensation unit, a liquid receiver and a rotary vacuum pump.

**Table 2.3. Experimental set-up components and their specifications**

<table>
<thead>
<tr>
<th>Components</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed Bed Reactor</td>
<td>Serial No. NC 5305 Model No. EN H 12 Q RATING: 3.0 KW SUPPLY: 230 V Maximum Temperature: 1400°C Length: 70.5 cm Breadth: 35.5 cm Width: 35.5 cm</td>
</tr>
<tr>
<td><img src="image" alt="Figure 2.5. Tube furnace or fixed bed reactor" /></td>
<td></td>
</tr>
<tr>
<td>Stainless Steel Tube</td>
<td>Length: 78.4 cm Effective length: 75.2 cm Diameter: 4.4 cm Effective diameter: 3.7 cm</td>
</tr>
<tr>
<td><img src="image" alt="Figure 2.6. Stainless steel tube of the fixed bed" /></td>
<td></td>
</tr>
</tbody>
</table>
### Rotary Vacuum Pump

- Model No.: SSRP/30 (Single stage)
- Pump No.: 581
- RATING: ¼ H.P. (0.18 KW)
- Normal RPM: 550
- Manufactured by: Basic & Synthetic Chemical Pvt. Ltd., Jadavpur, Kolkata – 700 032

![Figure 2.7. Rotary pump and its pump motor](image)

### Pump Motor

- Model No: FP 2G17B (CLASS A INS.)
- Serial No. 100V475
- Frame: B 56 (BS: 2048-1) IS: 996/ BS: 5000
- Type: Continuous Rating CSIR type
- Rating: ¼ H.P. (0.18 KW)
- Normal RPM: 1440
- Supply: 220/240 V, 50 Hz, 2.4 Amps
- Manufactured by: American Universal Electric (India) Ltd., Faridabad, Haryana.

### Complete set-up

![Figure 2.8. Complete setup for pyrolysis product extraction](image)
2.8. Experimental Procedure

The experimental procedure consists broadly of three steps i.e. Pre-treatment, Incineration and Sample collection.

2.8.1. Pre-treatment

Before beginning the experiment, some weighted amount of rice-husk was needed. This weighted rice husk of 150 grams was dried properly in the Sun. Then it was fed to the tube furnace through the stainless steel tube. The moisture content before the rice husk is sun dried was found to be 11.15%. The table below details the percentage in which these parameters are present in the rice husk.

<table>
<thead>
<tr>
<th>Constituents of Rice husk</th>
<th>% of the constituents by weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture</td>
<td>11.15</td>
</tr>
<tr>
<td>Volatile Matter</td>
<td>58.03</td>
</tr>
<tr>
<td>Fixed Carbon</td>
<td>10.94</td>
</tr>
<tr>
<td>Ash</td>
<td>19.88</td>
</tr>
<tr>
<td>TOTAL</td>
<td>100</td>
</tr>
</tbody>
</table>

2.8.2. Incineration

The procedure for the purpose is as follows:

(a) A definite amount of sun-dried rice husk was taken in a glass container and measured.
(b) The amount of the rice husk was limited to 150 grams.
(c) This weighted amount of rice husk was taken in the stainless steel tube, which in turn was fed to the fixed bed reactor or the tube furnace.
(d) The whole system was sealed with the help of Teflon tape in order to make the system air tight so that air cannot enter the system.
(e) The system was connected with power supply at two points; one from the rotary vacuum pump and the other from the tube furnace.
(f) Now the rotary vacuum pump was turned on for around 20 minutes so that all the air present beforehand gets ejected out and the system becomes partially vacuumed.

(g) As soon as the air leaving rate at the exhaust point of the pump becomes negligible, the reactor was tuned on, as maximum of the air or gases has been pulled out from the confined area, making the area vacuum. This helped the rice husk that was fed to the tube furnace, to be heated up in a controlled atmosphere.

(h) This experiment was conducted at a heating rate of around 12°C per minute.

(i) The incineration temperature range was kept limited from 300°C - 700°C and it was found that the maximum incineration time in the reactor was 1.5 hours.

(j) This process resulted in the evolution of gas and vapours, which were passed through a spiral tube water-cooled condenser. The spiral shape was chosen for this experiment for the sole reason of allowing the gas to have more contact time with the ice and cold water. This was previously attached with a liquid receiver, in which the pyrolysed oil was gradually being accumulated. Generally, the droplets began getting collected in the glass flask after around 200°C.

(k) The pyrolysed oil is obtained along with gas and ash. The ash was left untouched for around 24 hours and then taken out of the tube furnace, while the gas produced during the process was fed into the atmosphere.

2.8.3. Sample collection

Three outputs were noticed from the conducted experiment. These are pyrolysed Oil, ash and gas.

2.9. Observation

Quantity of Rice husk taken (R) = 150 gm
Table 2.5. Observation table to find the percentage of oil yield

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Operating Temperature (°C)</th>
<th>Weight of Collected pyrolysed oil (gram)</th>
<th>pH of the liquid</th>
<th>Oil yield (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>300 – 350</td>
<td>45.54</td>
<td>2.87</td>
<td>30.36</td>
</tr>
<tr>
<td>2</td>
<td>400 – 450</td>
<td>43.03</td>
<td>2.91</td>
<td>28.68</td>
</tr>
<tr>
<td>3</td>
<td>500 – 550</td>
<td>34.75</td>
<td>2.92</td>
<td>23.17</td>
</tr>
<tr>
<td>4</td>
<td>550 – 600</td>
<td>31.53</td>
<td>4.01</td>
<td>21.02</td>
</tr>
<tr>
<td>5</td>
<td>600 – 650</td>
<td>30.66</td>
<td>4.04</td>
<td>20.44</td>
</tr>
<tr>
<td>6</td>
<td>650 – 700</td>
<td>30.56</td>
<td>4.04</td>
<td>20.37</td>
</tr>
</tbody>
</table>

From table 2.4 and figure 2.9, it can be observed that the weight of pyrolysis oil remains nearly constant from 300°C -450°C. The optimum oil yield is obtained within this temperature range. Gradually there is a decrease in oil yield with the rise in temperature.

![Graph of operating temperature vs percentage oil yield](image)

Fig 2.9. Graph of operating temperature vs percentage oil yield

2.10 Mathematical analysis

The calorific value of bio-oil has been calculated using the formula:
m_f. CV = m_e. C_{pe.} (T_f - T_i)_{corrected} \quad (2.3)

where \( m_f \) = mass of fuel burnt in gram

\( m_e \) = equivalent mass of water and bomb calorimeter in gram

\( C_{pe} \) = equivalent specific heat of water and bomb calorimeter in cal/°C

\((T_f - T_i)_{corrected} = (\text{Final temperature} – \text{Initial temperature})_{corrected}\)

\(= (\text{Temperature difference observed}) - (\text{effect of heat added due to stirrer}) + (\text{effect of heat loss to ambient environment})\)

2.11 Sample Calculation

Mass of crucible + Mass of fuel sample = 8.5822 gram

⇒ 7.5622 gram + Mass of fuel sample = 8.5822 gram

⇒ Mass of fuel sample = (8.5822 – 7.5622) gram

⇒ Mass of fuel sample = 1.02 gram.

Equivalent mass and specific heat of water in bomb calorimeter = 3695.92 cal/°C

This is calculated after the standardization test.

\((T_f - T_i)_{corrected} = 2.13°C\)

The heat balance equation is given by:

Heat liberated from fuel = Heat gained by water and bomb calorimeter

From (2.3), \( m_f. CV = m_e. C_{pe.} (T_f - T_i)_{corrected} \)
Hence, from equation (2.3), it can be written that:

$$CV = \frac{3695.92 + 2.13}{1.02} \text{ cal/gram-}^\circ\text{C}$$

⇒ CV = 7717.95 cal/gram-°C

As the fuel comprises of conventional diesel and RS-oil in the ratio of 1:1, hence, the calorific value of RS-oil sample = \[2 \times \{7717.95-(10000 \times 0.50)\}\] cal/gram

= 5435.9 cal/gram-°C = 22.74 MJ/kg-°C

2.11.1 Impact

Rice occupies 44.5 lakh ha. land of Odisha.
Yield rate of rice = 1.6 tonnes/ha = 71.28 lakh MT rice
Practical rice yield = 69.16 lakh MT
Assuming 50% of this comes to rice mills = 34.58 lakh MT
22% is Rice husk
3% is immature paddy
So, total rice husk is = \(\frac{25}{100} \times 34.58\) lakh MT = 8.645 lakh MT
1.25 kg rice husk gives 1 kWh electricity
Hence, 8.645 lakh MT rice gives \(\frac{1}{1.25} \times 8.645 \times 10^5\) kWh electricity = 6915 \times 10^5 kWh electricity

2.11.2 Coal Savings

1 kWh of electricity is produced by 600 g of coal
6915 \times 10^5 kWh electricity is produced by = 4149600 \times 10^5 g of coal
\[= 4149.6 \times 10^5 \text{ kg of coal}\]

2.11.3 Carbon dioxide savings

600 g coal produces 1.2 kg CO\(_2\)

\[\Rightarrow 4149.6 \times 10^5 \times 10^3 \text{ g coal produces } \frac{12}{600} \times 4149.6 \times 10^5 \times 10^3 \text{ Kg CO}_2 = 8299.2 \times 10^5 \text{ kg CO}_2\]

2.12 Characterization of the extracts

The extracts that have been collected by the experiments mentioned in the previous sections were examined for both physical and chemical parameters. In the physical tests, the following parameters of the bio-oil were studied: Water, Specific gravity, heating value, % of solid, viscosity, pH and oxygen percentage. And chemical characteristics studies were conducted to see the chemical composition of the content that was collected from the extracts of oil seed and they are compared with the crude oil extracted from the deep [96 - 98]. Results show the data for the extracts for the following table.

**Table 2.6 Comparison table**

<table>
<thead>
<tr>
<th>Physical property</th>
<th>Oil from rice husk</th>
<th>Pyrolysis Bio-oil</th>
<th>Heavy Fuel Oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water, wt%</td>
<td>25-40</td>
<td>15-30</td>
<td>0.1</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>1.11</td>
<td>1.2</td>
<td>0.94</td>
</tr>
<tr>
<td>Heating Value (MJ/kg)</td>
<td>9-10</td>
<td>13-19</td>
<td>40</td>
</tr>
<tr>
<td>Solids, wt%</td>
<td>0.2-0.1</td>
<td>0.2-0.1</td>
<td>0.2-1.0</td>
</tr>
<tr>
<td>Viscosity (at 50°C) (C(_p))</td>
<td>30-80</td>
<td>40-100</td>
<td>180</td>
</tr>
<tr>
<td>pH</td>
<td>2.5</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td>Oxygen, wt%</td>
<td>35-50</td>
<td>35-60</td>
<td>0.6-1.0</td>
</tr>
</tbody>
</table>

These data indicate that the extracted oil and some of the chemical components can be extracted using the partial distillation process. Oil can be collected and blended with
conventional diesel to conserve diesel quality [101, 102]. Similarly, the oil can be used for manufacturing paint and anticorrosive material. So, these are the real outcome of the experiment.

2.13 Conclusion

The synthetic gas produced from the rice husk of the rice mill was fed into a biomass downdraft gasifier coupled with a dual fuel generator to produce electricity. At optimum condition, generator used 70% syngas and 30% diesel. The gasifier-dual fuel generator system from the field study has been improved by using electrostatic precipitator and cyclone combined with dual layer granular bed filter. Tar is a byproduct of this gasification process and is considered as a waste. This extract was collected and examined for both physical and chemical parameters. In the physical tests, water content, specific gravity, heating value, percentage of solid, viscosity, pH and oxygen percentage were studied and were compared with the crude oil extracted from the deep. The results validated the possibility of using blended form of this extraction which can be fed to the dual fuel generator replacing the diesel oil. Conventional methods for oil extraction use the pressing and nearly 30% of the oil remains in the oil cakes and then used as cattle-feed or fertilizer. However, in this method, no oil was left in the oil cake and the solid compound remains as oxide material which can have further application in the industries. In addition, calculation has been shown in the saving of coal and carbon dioxide by using biomass with gasification technology.