Evaluation of Torrefaction Pilot Plant in Klintehamn, Gotland

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Abstract

Torrefaction is a thermal treatment of biomass in a range of 200-300°C. The reactor is kept under an oxygen free environment to avoid combustion of the biomass. Torkapparater has developed a Torrefaction process which has been tested and evaluated during a series of test in a pilot plant located in Klintehamn, Gotland. The reactor consists of a rotating drum, a tubular, which is heated indirectly by flue gases produced in a biosolids furnace. The trials shows that the process works as intended although the gas handling system needs further development. The produced torrefied biomass shows the expected characteristics such as brittleness, higher carbon content and calorific value.

Keywords: Torrefaction, Biomass, Pilot Plant, Mass- and Energy balance, Renewable Fuel

Introduction

The interest of renewable fuel has increased in recent time and one possibility is to use torrefied biomass as a fuel in power plants that is currently using coal as a fuel. Raw biomass cannot replaced coal as fuel in existing power plants in a large scale sins it has a low bulk density, high moisture content, hydrophilic nature and a low calorific value. [1] All of these characteristics cause needs in handling of very high volumes which creates problems regarding storage, transportation and feed handling at cogeneration, thermochemical and biochemical conversion plants. [2]

To test and evaluate the potential to torrefie biomass in a larger scale, a pilot plant for torrefaction has been set up and operated in Klintehamn, Gotland during the spring and summer of 2012. This article will give an overview of the plant and the torrefaction process as well as a presentation of the trials that has been made so far. The main conclusion to be drawn from the experiments at the pilot plant in Gotland is that the torrefaction process developed by AB Torkapparater is working as it was intended.

Torrefaction

Torrefaction is a thermal treatment of biomass in a temperature range of 200-300°C; the process is often referred to as a mild pyrolysis. The reactor is kept under an oxygen free environment to avoid combustion of the biomass and the process if regularly operated at atmospheric pressure.

Torrefaction will reduce the energy needed to grind the biomass and also increase the calorific heat value and energy density of the product compared to untreated biomass.

Two parameters that often occur as a comparison of torrefied product produced in different processes is mass- and energy yield. The following definitions of mass- and energy yield have been applied in the evaluation of this process, see equation 1 and 2 [3].
\[ y_M = \frac{m_{torrefied}}{m_{feed}} \]  

\[ y_E = y_M \cdot \left( \frac{LHV_{torrefied}}{LHV_{feed}} \right) \]

**Process**

The reactor consists of a rotating drum, a tubular, which is equipped with 72 pieces of tubes. The rotor is disposed in a casing and hot flue gases flows through both the casing and the tubes. Flue gases are supplied to the system through a mixing chamber where flue gases from an existing bio solids furnace is mixed with a part of the outgoing flue gases from the reactor in order to obtain the desired temperature in the mixing chamber.

In the inlet and outlet end of the reactor, a specially designed seals with a flow of nitrogen is placed as an additional step to obtain an oxygen-free reactor space. Rotary valves are used both at the inlet and outlet of the reactor in order to prevent air leakage. Flue gases at a temperature of approximately 220°C is supplied in a small amount in between the two rotary valves to reduce the amount of oxygen going in to the reactor space. In outlet end of the reactor, the material is passed through an outlet rotor neck and an outlet chamber. The material is discharged at the bottom of outlet chamber and passed through a mill before it is feed to the pellet press.

The torrefaction gas is charged at the top of the outlet chamber. The outlet chamber is double jacketed and heated indirectly by flue gases to avoid condensing of tar inside the chamber. During startup of the process, before the torrefaction temperature is reached, the gas is led out to the surroundings through a stack. When the temperature has reached 180-200°C, a valve is switched and the gas is directed through a dust trap onto a fan and a venturi, which measures the flow, and introduced into a bio solids furnace for combustion. The gas is injected into the top of the bio solids furnace were the temperature is at its highest, about 1200°C, to ensure that the gas is completely combusted.

The torrefaction gas condenses very easily and therefore all gas channels are heated to about 300°C to avoid clogging of pipes and other equipment. Even the slightest bump, edge or particle in the system will allow the gas to condense and smudge the system. Where it is possible, the torrefaction gas pipe is lead inside the flue gas pipe, which provides heat to the process, this keep the torrefaction gas pipes at a high temperature and condensation of the torrefaction gas is avoided. Where it is not possible to conduct the pipes similar, the torrefaction gas pipe is heated using an electrical heating wire.

An analysis loop is attached to the gas handling system. The gas is led through a condenser and the tar compounds is sampled in a jar and sent to a lab where the calorific heat value is analyzed. The non-condensable gases is sampled in a gas-tight bag and sent to lab for analyzing.

**Results**

Major focus has been put into an evaluation of experiments conducted during the trials performed in the 19th of June. The achieved mass- and energy yield for the torrefied product produced in the 19th of June has been calculated and the material that was used in this trial was the Latgran mix which is a mixture of flaked hardwood and softwood combined with sawdust. The mass yield was measured to be 82% of the ingoing raw material at a torrefaction temperature of 250°C and 85% at a torrefaction temperature of 260°C. The energy yield was also determined for the process and 92% of the energy content of the ingoing raw material was obtained in the torrefied product at 250°C and the corresponding value at 260°C was determined to 95% of the ingoing energy in the raw material. Two other materials were used but the Latgran mix is the only material so far that has been fully analyzed.

The total energy need in the process was calculated for the different operation points and the process requires 1627 kJ/kg torrefied
Latgran mix at a torrefaction temperature of 250°C and 1498 kJ/kg at a torrefaction temperature of 260°C. The produced torrefaction gas will be burnt and restored as heat in the process and if the gas is burnt, assuming 20% heat losses in the furnace, the need of external energy input to the process will be lowered to 1177 kJ/kg torrefied product at a torrefaction temperature of 250°C and 1074 kJ/kg if the plant is operated at 260°C. The results of the mass- and energy balances are summarized in Table 1 and 2 below.

Table 1, Summary of the mass- and energy balances for the torrefaction trial performed during the 19th of June at 250°C.

<table>
<thead>
<tr>
<th>Torrefaction temp.</th>
<th>250°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass yield</td>
<td>82%</td>
</tr>
<tr>
<td>Energy yield</td>
<td>95%</td>
</tr>
<tr>
<td>Ingoing biomass</td>
<td>345 kg/h 11.3 wt% moisture</td>
</tr>
<tr>
<td>Outgoing product</td>
<td>252 kg/h</td>
</tr>
<tr>
<td>Supplied Energy (from flue gases)</td>
<td>112 kW</td>
</tr>
<tr>
<td>Potential energy to recover from torrefaction gas</td>
<td>39 kW</td>
</tr>
</tbody>
</table>

Table 2, Summary of the mass- and energy balances for the torrefaction trial performed during the 19th of June at 260°C.

<table>
<thead>
<tr>
<th>Torrefaction temp.</th>
<th>260°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass yield</td>
<td>85%</td>
</tr>
<tr>
<td>Energy yield</td>
<td>95%</td>
</tr>
<tr>
<td>Ingoing biomass</td>
<td>364 kg/h 11.3 wt% moisture</td>
</tr>
<tr>
<td>Outgoing product</td>
<td>274 kg/h</td>
</tr>
<tr>
<td>Supplied Energy (from flue gases)</td>
<td>112 kW</td>
</tr>
<tr>
<td>Potential energy to recover from torrefaction gas</td>
<td>66 kW</td>
</tr>
</tbody>
</table>

Trials have been made to pelletize the torrefied product. The best result was achieved in the 10th of May, when a sawdust mix was torrefied at approximately 245°C. These pellets were produced by only adding water to the torrefied material. Other trials were made to pelletize material torrefied at a higher torrefaction temperature unfortunately with an unsatisfying result. The pellets made during these trials were very short and had poor durability. Further experiments will be performed on Gotland and one of the goals will be to produce good quality pellets.

**Conclusions**

The torrefaction process developed by Torkapparater works as it was intended. Although, one part of the process is still in need for further development and that part is the gas handling system. The gas produced in the pilot plant in Gotland is combusted in an existing biosolids furnace to recover energy from the produced gas as heat to the process, the same concept is planned to be used in a future full-scale plant. The problem in the system at this moment is not the combustion itself, but rather the transportation of the gas to the combustion. Even the smallest edge or particle in the system allows the gas to condensate and creating a layer of tar on the surfaces in pipes and other equipment. Therefore, it is important to minimize the entrainment of dust and particulates into the gas stream from the reactor, but also to provide the shortest transportation distance as possible from the reactor outlet to the combustion. Moreover, transport distance must be maintained at at least the same temperature or higher than the reactor space to avoid condensation caused by temperature drop in the system.

The product which was obtained has shown the properties that are expected for a torrefied material, for instants the carbon content increases when torrefaction temperature increases, see Figure 1.
Furthermore the calorific value of the product increases with a higher carbon content, see Figure 2, which is perfectly reasonable and in line with other torrefaction projects.

The produced material is brittle and has a uniform color throughout the particles and shows hydrophobic properties in comparison to dried biomass.

References

