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TRI BIOMASS GASIFICATION TECHNOLOGY – HOW IT WORKS

Introduction

TRI's proprietary biomass gasification technology employs indirectly heated steam reforming to convert any carbonaceous feedstock into high quality synthesis gas ("syngas") for the production of value added products such as fuels and chemicals. With biomass feed, carbon neutral or even carbon negative biofuels and biochemicals can be produced.

Biomass steam reforming and gasification are terms often used interchangeably. Although they are closely related thermochemical processes, they have different technical definitions. Gasification is the more general process of sub-stoichiometric oxidation (partial oxidation) of a biomass feedstock to produce a gaseous mixture containing carbon monoxide, hydrogen, carbon dioxide, methane and other hydrocarbons. By limiting the oxygen available, the main reaction is exothermic and based on the following:

$$2C + O_2 = 2CO + heat$$

Methane, hydrogen and hydrocarbons are released during the pyrolysis of the biomass.

Steam reformation is a specific chemical reaction whereby steam reacts with organic carbon to yield carbon monoxide and hydrogen. TRI has commercialized indirectly heated biomass steam reforming. The first two commercial installations of the TRI technology have used black liquor as the biomass feedstock. In the TRI steam reforming system the main reaction is endothermic as follows:

$$H_2O + C + heat = H_2 + CO$$

Steam also reacts with carbon monoxide to produce carbon dioxide and more hydrogen through the water gas shift reaction:

$$CO + H_2O = H_2 + CO_2$$

During the biomass drying and heat-up process, volatile components are released (pyrolysis) in the form of methane, hydrogen, carbon monoxide, carbon dioxide and other hydrocarbons. The result is a medium Btu hydrogen-rich syngas that can be used to produce one or more of the following: (1) biofuel and/or biochemical through catalytic or fermentation pathways, (2) steam by combustion in a boiler, and (3) power by combustion in combined cycle gas turbine or processing through a fuel cell.

TRI Proprietary Technology

TRI utilizes a two step biomass gasification process based on the endothermic steam reforming reaction, but can supplement with a small fraction of exothermic partial oxidation reactions to adjust the H_2 to CO ratio in the synthesis gas to meet the requirements of the downstream syngas conversion processes.

The TRI biomass gasification technology employs a deep steam fluidized bed that is indirectly heated with pulsed combustion heat exchangers (PC Heaters) that are fully submerged inside the fluid bed as shown in figure 1. Regardless of the feedstock, the process has three inputs and three outputs.

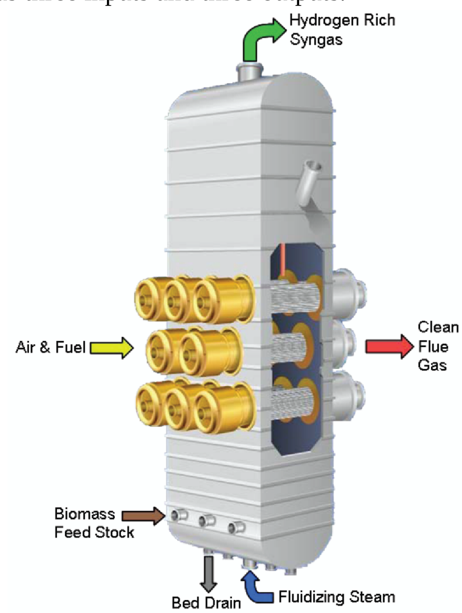

Figure 1 – TRI Steam Reformer

The bed material will depend on the application; for liquid biomass feedstocks such as black liquor, the bed material will be sodium carbonate, the recovered inorganic chemicals from the liquor, but for solid biomass feedstocks such as forest or agricultural residuals, the bed will be sand, alumina oxide or other inert media. The bed material is fluidized by introducing superheated steam (input 1), and is indirectly heated with a fuel source in the PC Heaters (input 2). Once the bed reaches operating temperature, biomass is introduced into the bed

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(input 3). The three outputs are hydrogen-rich syngas, clean flue gas and dry bed drain. The bed operating temperature is selected based on the feedstock properties, but will always be below the slagging temperature of any components in the biomass. Once the biomass is introduced into the bed and heated, the remaining moisture will evaporate, followed by pyrolysis where volatile components are released and the resultant char will undergo steam reforming.

Click on the image below to view a short animation of how the steam reformer works:

Click Image to View Animation

The reformer bed level covers the PC Heaters and will contain a large mass of bed media, which acts as a thermal flywheel for the process. Because of this unique attribute, the reformer can process a wide spectrum of feedstocks and is insensitive to fluctuations in biomass feed rate, moisture content and Btu value. This together with operating in the converging regime because of endothermic steam reforming reactions, makes the TRI system extremely stable, even at very high turn-down ratios.

By providing the endothermic energy required for the steam reforming reactions indirectly, the resulting syngas is not diluted with any combustion products, and the process yields a medium Btu syngas. The endothermic heat load for the steam reforming reaction is relatively large, and the ability to deliver this indirectly in an efficient manner lies in the use of pulse combustors.

Pulse combustion was originally developed by the Germans as the propulsion system for rockets. Key elements of pulse combustion have been incorporated in the TRI design to provide high heat transfer instead of thrust. The pulse combustors operate on the Helmholtz Resonator principle as described below. The components of the pulse combustor are shown in Figure 2.

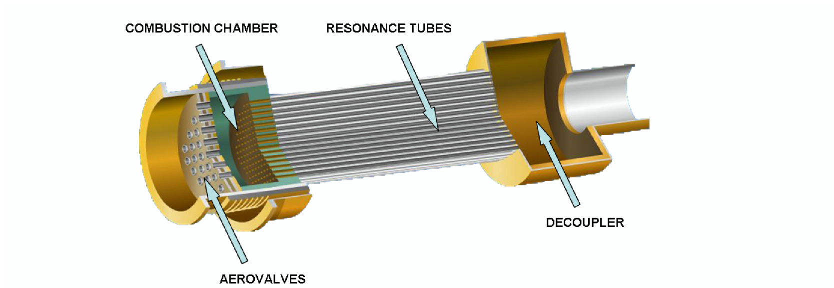
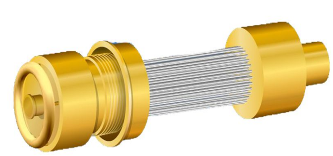


Figure 2- PC Heater Cut-Away Section

Air and fuel are introduced into the combustion chamber with flow control through proprietary aerovalves, and ignited with a pilot flame; combustion of the air-fuel mix causes expansion, and the hot gases rush down the resonance tubes, leaving a vacuum in the combustion chamber; the vacuum aspirates more air and fuel into the chamber, but also causes the hot gases to reverse direction and flow back towards the chamber; the hot chamber breaching and the compression caused by the reversing hot gases ignite the fresh air-fuel mix, again causing expansion, with the hot gases rushing down the resonance tubes, leaving a vacuum in the combustion chamber. This process is repeated over and over at the design frequency (typically 60 Hz, or 60 times per second). In essence, this is a two stroke engine, but with no moving parts. An animated sequence of these events is shown in the following animation – click on the image below to start the animation.



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Only the tube bundle portion of the heater is exposed to the steam reforming process inside of the reformer vessel. Because the bundles are fully submerged in a fluid bed, the heat transfer on the outside of the tubes is very high (fluid beds by their nature have inherently high heat transfer coefficients). The resistance to heat transfer is on the inside of the tubes. However, since the hot flue gasses are constantly changing direction (60 times per second), the boundary layer on the inside of the tube is continuously scrubbed away, leading to a significantly higher inside tube heat transfer coefficient as compared to a conventional fired-tube. The result is an overall heat transfer that is an order of magnitude higher than conventional combustion systems. Other advantages of the pulse combustion are:

- Very high combustion efficiency because of superior fuel/air mixing, compression/ignition sequence and built-in flue gas recirculation
- Low NOx because of short residence time at high temperature, well stirred tank reaction mode and flue gas recirculation
- Near uniform heat flux down the length of the tube due to pulsating/oscillatory flow field and residual combustion
- Fuels flexibility; the system can be designed to operate on natural gas, on internally generated syngas or on waste tail gas from downstream synthesis processes

Summary

By combining the attributes of low temperature indirectly heated steam reforming with high heat flux pulse combustion, TRI's proprietary biomass gasification technology offers the following benefits over other gasification systems:

- Generates a medium Btu hydrogen-rich syngas.
- Can process a wide spectrum of carbonaceous feedstocks including forest and agricultural residuals, black liquor, industrial wastes and sludges, construction demolition debris, animal wastes such as poultry litter, swine waste and cattle manure and MSW derived fuels, etc
- Can customize the syngas H_2:CO ratio to meet the requirements of any downstream synthesis or fermentation process for the production of value added biofuels and biochemicals.
- The system is non-slagging and the bed drain is dry. (Avoids smelt-water explosions associated with black liquor)
- The process is very stable, has high turndown ratio and is simple to operate.
- Is energy self-sufficient in using waste tail gas or internally generated syngas as fuel for pulse combustors.
- The technology has ultra low emissions due to syngas clean-up and pulse combustion.

The various applications of the technology that take advantage of the unique attributes of the TRI steam reforming process are described in the Applications sub-tab of the TRI Web page under Technology tab. These include the Integrated Biorefinery for biofuels and biochemicals; black liquor gasification; fossil fuels displacement; combined heat and power and fuel cells.

Please contact TRI at the above numbers if you require more information on this ground breaking technology and its applications.