ADVANCED BIOMASS GASIFICATION FOR THE ECONOMICAL PRODUCTION OF BIOPOWER, FUELS, AND HYDROGEN -- IMPLEMENTATION IN MONTGOMERY, NEW YORK

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ABSTRACT: Recent price increases for various forms of energy along with projected shortages of supply have resulted in renewed interest in alternative fuels. Biomass gasification provides a renewable basis for supplying not only direct energy products such as gaseous and liquid fuels, and electric power, but also a broad suite of chemicals such as Fisher-Tropsch liquids as well as hydrogen. A medium calorific value (MCV) gas is necessary to achieve the full potential of biomass gasification for fuels, chemicals, and hydrogen production. The Taylor gasification process, being developed by Taylor Biomass Energy is a biomass gasification process that produces a MCV gas. The Taylor gasification process provides improvements over currently available gasification processes by integrating improvements to reduce issues with ash agglomeration and provide in-situ destruction of condensable hydrocarbons (tars), an essential element in gas cleanup. The gas conditioning step integrated into the Taylor Gasification Process provides a unique method to convert the tars into additional synthesis gas and to adjust the composition of the synthesis gas to significantly increase its hydrogen to carbon monoxide ratio. Testing has shown that approximately 90% of the tars can be removed by the gas conditioning step providing a synthesis gas suitable for a variety of applications.

Construction is expected to start in mid 2007 for an integrated combined cycle power system incorporating the Taylor Gasification Process and utilizing biomass feedstocks recovered from municipal solid wastes (MSW) and construction and demolition wastes (C&D). The Taylor Recycling Facility, LLC, located approximately 70 miles northwest of New York City in Montgomery, NY, is a leader in C&D and waste wood recycling. The plant with a current capacity of 350 tonnes per day, is operated continuously. The facility will consist of three primary elements: (1) an expansion of the Taylor Sorting and Separation system to produce biomass feedstock for the gasifier, (2) a 275 tonne per day (dry basis) Taylor Gasifier, and (3) a power island to convert the MCV gas into competitively priced electric power. In addition, the facility will provide a development platform where downstream unit operations such as chemical synthesis or hydrogen production can be easily evaluated. The design of the Taylor Gasification facility will allow the gasification island to be built in a modular-type of construction, providing faster installation of the gasification facility and reduced capital costs.

The Taylor Gasification Process, its modular design, and implementation into the commercial IGCC system in Montgomery, NY is discussed.

Keywords: gasification, integrated gasification combined cycle, biomass conversion

1 INTRODUCTION

To actively pursue commercial scale biomass based systems, an adequate, sustainable supply of appropriate biomass material is necessary. Biomass as a fuel source is widely obtainable, but, in many locations, is prohibitively expensive due to transportation costs, or local supply issues.

The disposal of MSW is becoming an increasingly serious problem throughout the United States. In the period 1990 to 2000, MSW generation rates have increased by 13 percent. When compared to 1980 levels, generation rates have increased over 50 percent. Large quantities of other solid wastes, commonly referred to as construction and demolition wastes (C&D) are also generated annually further increasing the problem.

When combined with the rising cost of conventional fuel supplies and the desire to provide dependable, environmentally friendly, sustainable energy supplies, these factors lead to the use of a flexible and efficient biomass conversion system.

Taylor Biomass Energy is constructing a facility at its site in the United States in Montgomery, New York to bring such a technology into the marketplace.

2 BACKGROUND

A significant limitation to the widespread use of biomass gasification for power or synthesis applications is the contaminants contained in the synthesis gas produced. These contaminants consist, primarily, of condensable hydrocarbons (tars) that restrict heat recovery from the gases and cause fouling of downstream equipment. One solution to the problem has been to use the gas hot in a boiler or other similar combustion device. Such end use, however, restricts the potentially efficiency of such systems and virtually eliminates both the use of high efficiency power production via gas turbines and the use of the gas for synthesis.

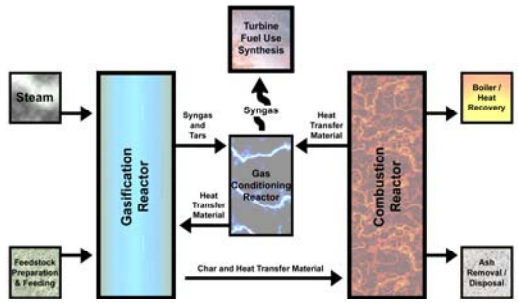
Taylor Biomass Energy has developed an advanced, indirectly heated gasification process that effectively converts the tars in the gas to non-condensible, lower molecular weight species. This removal allows a higher level of the sensible energy contained in the synthesis gas to be recovered while simplifying any secondary conditioning of the gas that might be necessary.

By building on the success of other indirectly heated gasification processes, the Taylor Gasification Process provides a m means to utilize the broad range of biomass feedstocks that are available while simplifying the

process of converting these biomass feedstocks into economically viable energy products.

3 THE TAYLOR PROCESS DESCRIPTION

In the Taylor Gasifier, a circulating heat carrying material is used to rapidly heat the incoming biomass and convey unconverted materials from the gasification reactor into an associated combustion reactor, as shown in figure 1 below.



1. Taylor Gasifier Schematic Diagram

In the gasifier, biomass is contacted by the heated heat carrying material, and steam. No air or oxygen is added so there are no combustion reactions taking place, providing environmental advantages. The biomass is rapidly (less than one second) converted into medium calorific value gas (14-17 MJ/Nm^3) at a temperature of approximately 850C. Any unconverted material along with the cooled heat transfer material, pass through the gasifier and then are separated from the product gas. The product gas continues on to the gas conditioning step prior to any final gas cleanup that might be needed while the solids are conveyed into the process combustion reactor.

In the combustion reactor, air is introduced which consumes the char and, in the process, reheats the sand to approximately 1000C. In the combustion reactor all remaining carbon is consumed, resulting in a carbon-free ash. Due to the combustion conditions and the fact that the unconverted material is essentially carbon, emissions are low from this step in the process. The reheated solids are separated from the flue gas and returned to the gasification reactor. Ash is removed from the flue gas, resulting in a high temperature (1000C) clean gas stream, available for heat recovery.

The gas conditioning reactor is the key element of the Taylor Process that provides enhanced gas compositions along with the improved heat recovery potential. Within the gas conditioning reactor, the product gas contacts the high temperature solids (1000C) providing an optimum environment for steam reforming of the tars. The tars are converted to lower molecular weight compounds that augment the quantity of synthesis gas produced.

The additional residence time provided by the gas conditioning reactor in the presence of a catalytic medium (the hot circulating solids) allows the synthesis gas to reach water gas shift equilibrium. As a result the hydrogen content of the synthesis gas is enhanced compared to other biomass gasification processes as shown in Table 1 below. The steam reforming reactions and the water gas shift reaction are balanced thermally so no cooling of the circulating solids takes place.

4 DEVELOPMENT OF THE PROCESS

The gasification and combustion steps within the process have been well developed by other organizations. To confirm the performance of the unique gas conditioning step, a series of tests were conducted at the National Renewable Energy Laboratory in their Thermochemical Users Facility (TCUF).

Table 1. Comparison of Gas Compositions With Other Indirect Gasification Processes

Component, o/v	Taylor	FICFB	SilvaGas®
Hydrogen	45-48	37.7	20.7
Carbon Monoxide	15-20	29.1	46
Methane	10-13	10.4	15.6
Ethylene	1-3	2.8	5.3
Carbon Dioxide	18-20	19.6	11.1
Ethane	0-1	0.3	0.7
Nitrogen	trace	0.1	0.6

This unit, while not in the exact configuration of the Taylor gasification process can be used to accurately simulate the process to allow determinations such as those for this study to be conducted. A description of the facility follows:

Thermochemical Process Development Unit

The Thermochemical Process Development Unit (TCPDU) is an integrated system of unit operations designed to investigate biomass thermochemical conversion to gaseous and liquid fuels and chemicals. The individual unit operations were designed to permit multiple equipment configurations. The ability to reconfigure the TCPDU permits operation over a wide range of conditions.

In the process configuration for gasification, the first and primary reactor in the process is an electrically heated 20.3 cm diameter fluidized bed reactor with a 40.6 cm (16") diameter freeboard. Product gas, entrained char, and bed material flow from the reactor through a pipe into a thermal cracker. The thermal cracker ensures that the raw composition of the product gas along with tars and other contaminants is appropriate for the gasification process being examined. Downstream of the thermal cracker are two cyclone separators in series that remove solids from the gas. The gas leaving the cyclones moves quickly into a "full stream tar reformer."

The Full Stream Reformer (FSR) shown in figure 2 below, is an electrically heated, 35.6 cm (14") diameter fluidized bed reactor with a 61 cm (24") diameter freeboard. Process gas from the gasification system is mixed with superheated steam or nitrogen as required and is then heated up to or near bed temperatures in a preheater. The reformed gas exits the FSR via an internal 11.4 cm (4.5") diameter cyclone. Entrained solids from the catalyst bed are collected by the cyclone and returned to the bed through a 4 cm (1.5") diameter dip leg. For this series of experiments, the full stream tar reformer was used to evaluate the Taylor "gas conditioning reactor".

This experimental system is outfitted with extensive analytical measurement devices. These include on-line gas chromatography and molecular beam mass spectrometer (TMBMS) to provide a continuous measurement of the process performance including concentrations of tar species present before and after the tar cracking operation.

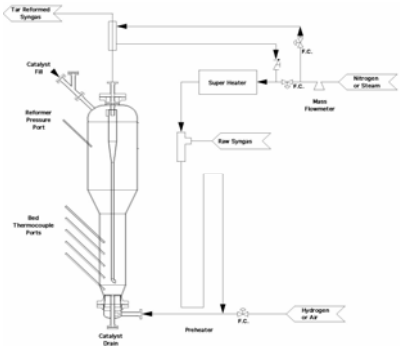


Figure 2. Full Stream Tar Reformer

5 EXPERIMENTAL RESULTS

Based on data measured using the TMBMS and on-line gas chromatography, tar conversion results showed between 80 an 90% conversion of nearly all species present. An increase in benzene was noticed, indicating that a portion of the tars was converted to this stable compound. This is not an unexpected result as the tars are primarily aromatic in nature and benzene is a very stable aromatic molecule. Figures 3 illustrates the tar conversion as a difference trace from the TMBMS.

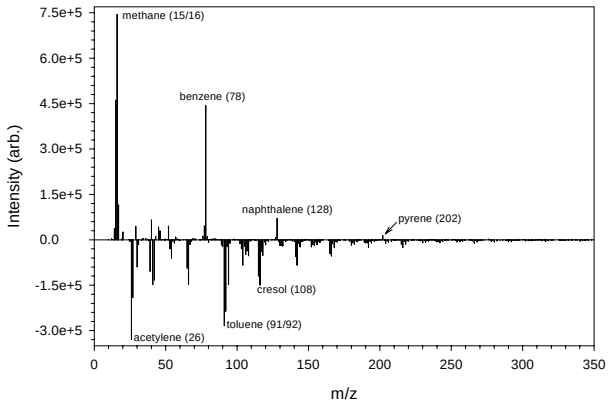


Figure 3. Difference Trace from TMBMS Showing Tar Conversion Results

5.1 Water Gas Shift Results

As discussed above, an additional benefit of the gas conditioning reactor, is the resulting increase in hydrogen content due to water gas shift equilibrium and the conversion of the tars into additional syngas. Table 2 shows the inlet and outlet composition of the synthesis gas illustrating this desirable result.

Such a change in composition allows the use of the syngas from the Taylor gasifier to be used directly for a much broader range of applications including the use for synthesis applications or for the direct recovery of hydrogen as an end product.

Table 2. Comparison of Gas Compositions at the Inlet and Outlet of the Gas Conditioning Reactor

Component, o/v	Inlet	Outlet
Hydrogen	29.5	47.2
Carbon Monoxide	30.1	17.4
Methane	14.4	12.2
Ethylene	3.9	2.6
Carbon Dioxide	20.7	20.1
Ethane	0	0.1
Nitrogen	trace	trace

5.2 Lifetime of Catalytic Performance

When applications rely upon the catalytic performance of a material, as in the Taylor gas conditioning reactor, there is always a question about the expected lifetime of the catalyst material. One primary cause of this deactivation in steam reforming type of reactions is the formation of carbon deposits on the catalyst surface. As the catalytic material in the Taylor Gasification Process is the circulating heat transfer material, such deactivation can not occur as the material passes alternately through an oxidizing regime and a reducing regime. This allows for in-situ regeneration of the catalyst thereby virtually eliminating the problem of catalyst deactivation.

During the testing at NREL, this “regeneration” of the material was evaluated. The “regenerated” material showed essentially the same tar conversion activity as the “virgin” material. This is illustrated in Figure 4 which shows the conversion performance on two consecutive days of operation. A “regeneration” of the material had taken place between the two testing periods.

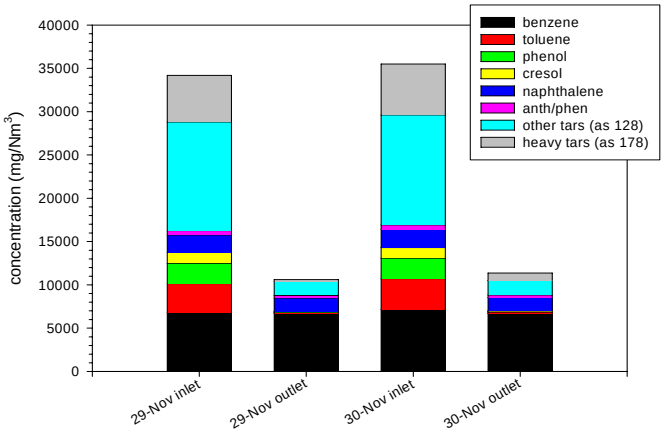


Figure 4. Consistent Performance of the Gas Conditioning Step

6 COMMERCIAL APPLICATION OF THE TAYLOR GASIFICATION PROCESS

The integration of the Taylor sorting, separating, and recycling process along with the Taylor Gasification Process is underway at the Taylor site in Montgomery, New York. At the site currently, approximately 275 tonnes per day of C&D material along with 90 tonnes of wood residues (stumps and similar materials) are sorted and a significant portion of biomass that would be suitable input to the gasification process is recovered. This existing operation will be expanded by approximately 50% and a sorting operation to handle

approximately 450 tonnes per day of municipal solid waste is being added. The combined operation will produce, on a sustainable basis, approximately 275 tonnes per day (dry basis) of a "processed biomass fuel" for the gasification process.

The Taylor gasifier will be constructed in a modular fashion rather than being completely assembled on site. This fabrication technique will provide much tighter control of the assembly as a well as provide capital cost savings during construction. Completed modules will be delivered to the site and erected with a minimum of installation necessary on site. A 3-D rendering of the assembled gasification process is found in Figure 5.

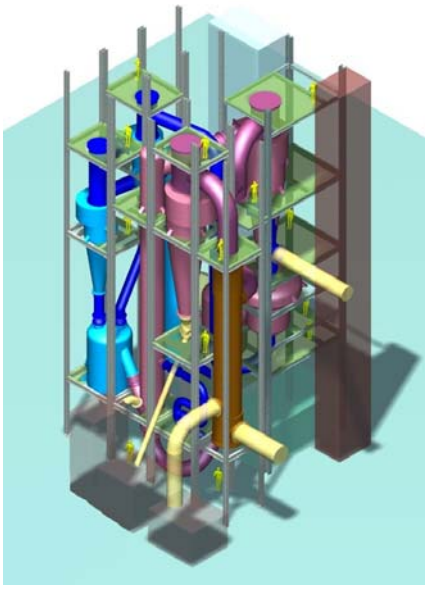


Figure 5. Layout of the Taylor Gasification Process

Syngas generated from the incoming biomass will be cleaned of particulates, compressed and used as fuel for a gas turbine based combined cycle power system. Approximately 20 MW will be exported from the facility to a local utility substation located on the site.

In addition, the facility will be constructed to provide a development platform where additional feedstocks and / or downstream unit operations such as chemical synthesis or hydrogen production can be readily demonstrated.

The Montgomery facility is underway with the Class A design package completed, permit documents in review, project financing in place, and initial site preparations completed. Detailed design is underway and construction of the gasification modules is expected to start shortly.

7 PROCESS ECONOMICS

The installed capital cost for the gasification island has been estimated to be between $550 and $600 per installed kW. Final costs for the power island have not been determined, but are expected to be consistent with state-of-the-art combined cycle facilities based on natural gas firing.

The facility at the Montgomery site will provide approximately 20 MW of power to the New York grid. This power is anticipated to be considered "renewable power" and therefore will be able to take advantage of various incentives available at the State and National level. Additional income to the project will accrue based on the sale of recyclable materials recovered from the incoming C&D and MSW streams and from tipping fees associated with the handling of these materials at the site.

Overall, the project is expected to be profitable in the very early years of the project life.

8 CONCLUSIONS

The Taylor gasification process has been shown to provide enhanced conversion of condensable organics by the integration of a unique gas conditioning step within the process. This step has been experimentally verified through testing at NREL and shows significant advantages when compared to downstream unit operations.

The commercial demonstration of the integrated Taylor sorting, separating, and recycling process with the Taylor gasifier has also shown that:

- A viable biomass resource can be supplied from residues including C&D materials and MSW
- Incorporation of these residue based biomass resources can be a key element in economical biomass energy projects
- A high quality synthesis gas can be produced from biomass without the need for multiple downstream process steps
- Biomass gasification can provide a route to a wide range of energy products including power, liquid fuels, chemicals, and hydrogen

Additional projects employing the Taylor gasifier and the Taylor sorting, separating, and recycling processes are in various stages of development. These projects are expected to be "on-line" within one year after the completion of the Montgomery, NY project.

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