Extended Abstact

For Session

Industrial Application of Computational and Numerical Approaches to Particle Flow (03B07)

"Industrial Application of CPFD to Biomass Gasification"

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AIChE Extended Abstract

SilvaGas Corporation converts wood chips, corn stover and other biomass feedstocks into a clean, medium BTU fuel which can be used directly in powerplant-sized gas turbine engines to produce electricity. The exhaust from the gas turbine can be used to generate more steam for additional electricity production, offering a combined cycle powerplant opportunity for electrical production from biomass feedstocks. The fuel gas is also clean enough to be used downstream in catalytic processes to make liquid fuels, such as the Fischer-Tropsch process, among others.

The SilvaGas process is an indirect gasification process, which pyrolyze the biomass in the absence of air or oxygen. The process was developed by Battelle in the 1980's, to take particular advantage of the high pyrolysis reactivity of biomass. The pyrolysis reaction is accomplished using two fluidized beds of hot sand in separate vessels.

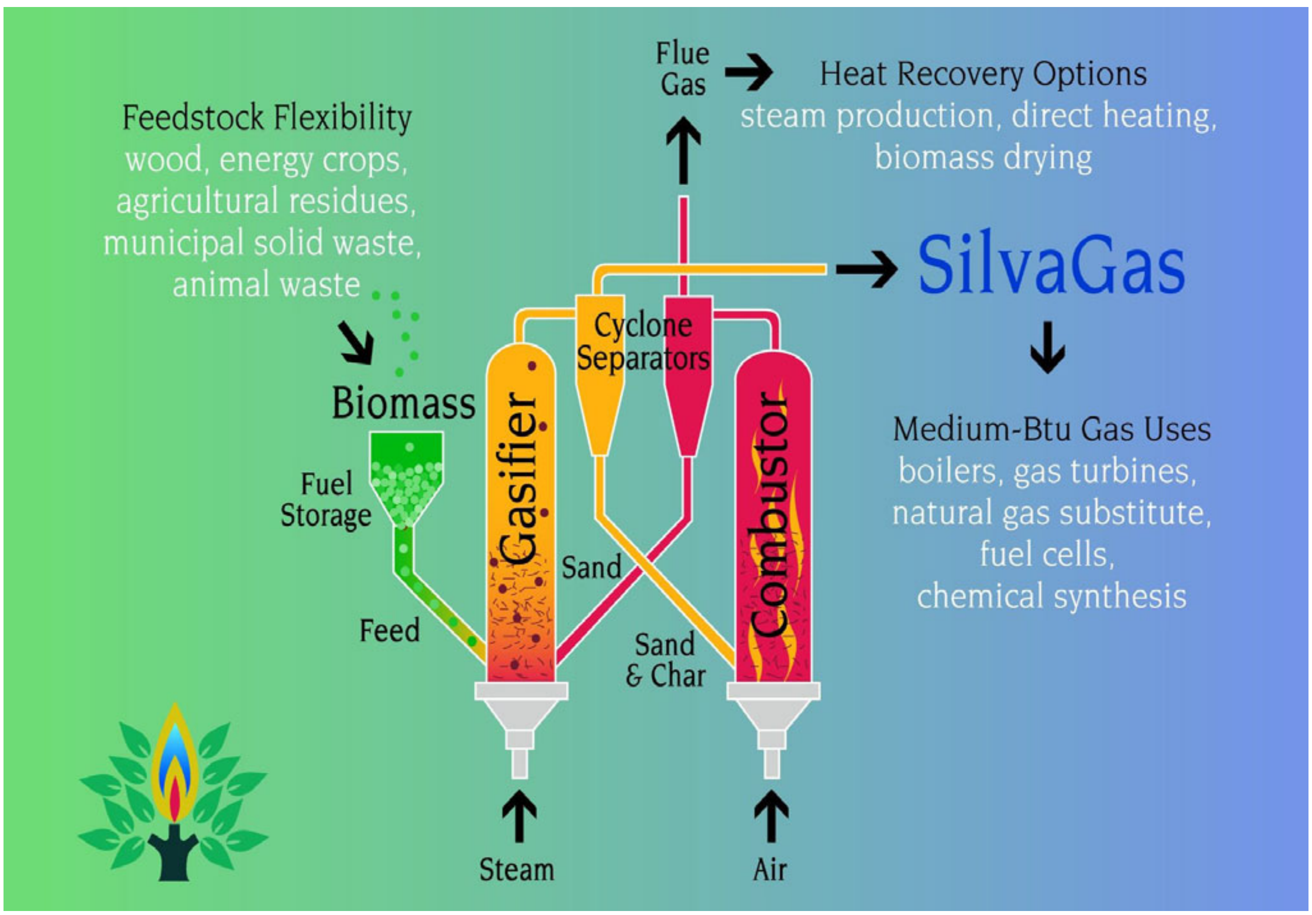

Figure 1
SilvaGas Process Schematic

Sand circulated through the system in a Figure 8 laid-on-its-side pattern. Wood enters the gasifier, and is pyrolyzed, releasing large amounts of gas. This entrains the 1700 deg F sand used to heat the wood upwards to a cyclone, where the sand and some char left over is separated from the fuel gas. The sand and char fall into a separate combustor, where the char is burned with air, reheating the sand, and entraining it overhead to another cyclone. The sand is separated from the ash and flue gas, which go overhead to downstream cleanup. The reheated sand goes back into the gasifier, repeating the process.

In many ways, the SilvaGas process is similar to petroleum FCC units.

A 400+ DTPD commercially-scaled pilot plant was operated from 1998-2001 in Burlington, Vermont, in a plant partially funded by the DOE.

Figure 2
SilvaGas 400 Dry Ton per Day Commercial Scale Facility

This plant accumulated a large amount of computer-based operating data on a wide variety of woody feedstocks. The data was used to quantifiably verify the accuracy of Barracuda prior to it being used for predictive purposes.

Once Barracuda was verified against our Burlington plant data, work was performed on improvements and scaleup studies for future, much larger plants.

The major process equipment which Barracuda has been used on for studies includes:

- The gasifier
- The combustor
- The gasifier cyclones
- The combustor seal pot

The Gasifier

Fluidized solids circulation in the gasifier is complex, with three separate identifiable zones. These are:

- The quiescent unfluidized zone of olivine at the bottom of the gasifier, below the steam fluidizing distributor
- The bubbling bed of olivine which receives the wood
- The entrained bed where the pyrolysis gases lift the sand, char and wood up into the top part of the gasifier.

Not much happens in the quiescent zone except the slow settling of dense, mostly iron contaminants to the bottom, such as nails, wire, and screws. These are drawn off in a batch approach, with the sand cooling to around 300F at the bottom drawoff.

The bubbling bed in the middle is short, at most a few feet in depth, with extremely high heat and mass transfer rates. The signature high biomass reactivity results in the explosive decomposition of the biomass, at rates from 10 to 30 times that of conventional coal fluidized bed combustors.

The fluidizing steam distributor was easy to model in Barracuda; what was harder to model was the decomposition of the wood, which releases roughly six times the volume of gases produced by the steam fluidization. This was modeling initially by adding an additional distributor above the steam distributor, to in effect act like the pyrolyzing biomass.

Barracuda was particularly effective in predicting the circulating patterns in the gasifier in the third section, the entrained bed section. It matched the pressure profile in the gasifier against operating data from the Burlington plant.

The combustor

The main effort here was to evaluate segregation of the char from the sand in the incoming feedline to better understand how to optimize feed distribution. Feed introduction in mature combustion technologies, like fluidized bed coal units, have as many as six feed points. The Burlington combustor was significantly larger than what was required, and is the most expensive vessel in the plant. Reducing its capacity to match that of the gasifier means requires better understanding of its reaction kinetics, and also, feed distribution.

The Barracuda software illustrated that the char in the char/olivine mix rapidly segregates in the feed line, with even more segregation happening once the char enters the combustor.

This is best seen in a movie, in the attached Powerpoint presentation. (This will be performed at the presentation.)

Cyclones

Cyclone design is a mature science, with lots of operational data. Barracuda runs on cyclones were also very time consuming, so less effort was expended on the cyclones with one exception.

Some texts have claimed that the gas/solids mixture flow exiting the top of a cylindrical vessel has a lot of kinetic energy, and that taking advantage of the kinetic energy in a vessel discharge flow can provide a useful separation strategy.

For instance, the high flow velocity of gases leaving the gasfier could be swirled to move the solids to the outer periphery and separated, without the need for a cyclone.

Such an approach was tried using Barracuda for the top head of the gasifier, to determine the relative efficiency of this approach. The approach worked, achieving 90% separation of the solids, but was rejected because the required pressure drop was about 4x that of an exterior cyclone, which would have achieved better than a 99.9% separation efficiency.

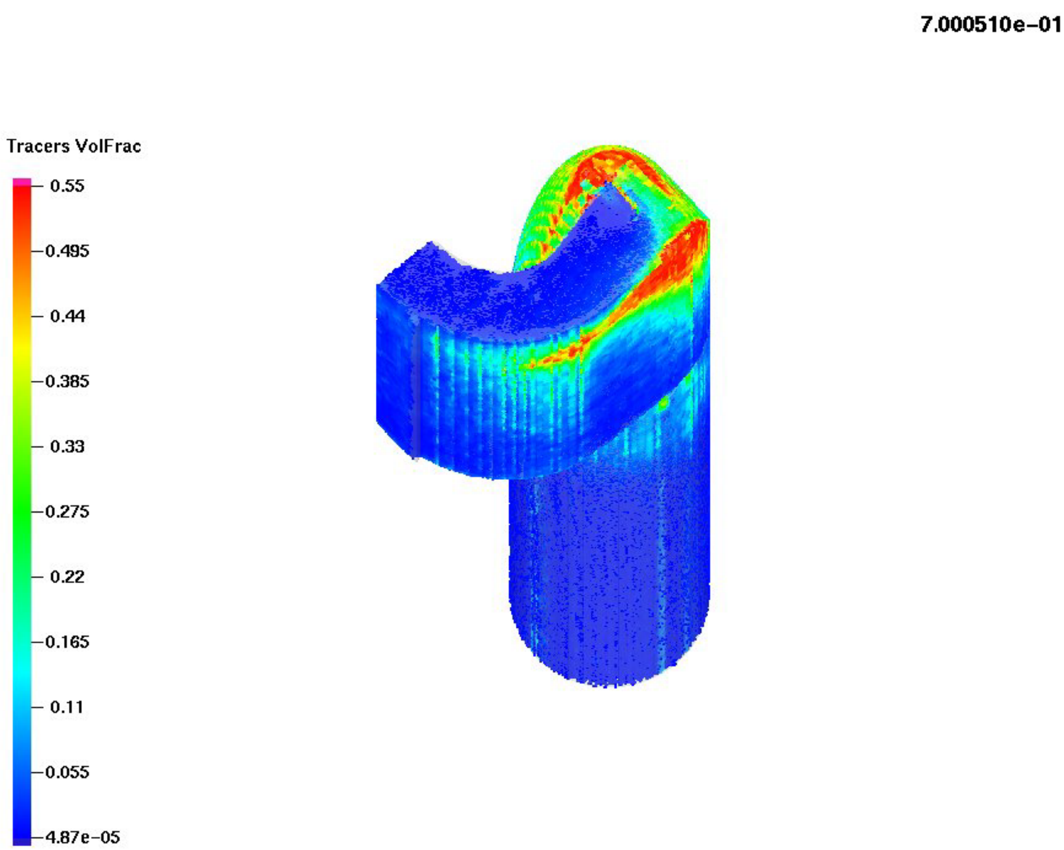

Figure 3
Color coded solids concentration in a swirled head gasifier

The above figure illustrates the variation in the solids volume fraction 0.75 seconds after starup. The red indicates approaching close pack of the olivine along the outer wall of the curved head.

Seal Pots

The gasifier operates at a higher pressure than the combustor. Thus, the transfer lines between the two vessels must be sealed, so that flammable gases from the gasifier train of equipment does not flow into the combustor train of equipment. This is accomplished by using fluidized bed seal pots.

There are distinct advantages to increased pressure operation of the gasifier train , while maintaining the combustor train at a minimum pressure above ambient. This requires a greater seal between the gasifier train and the combustor train, and this affects the design of the seal pots.

Barracuda has been a great help in the evolution of the seal pots used in SilvaGas design efforts.

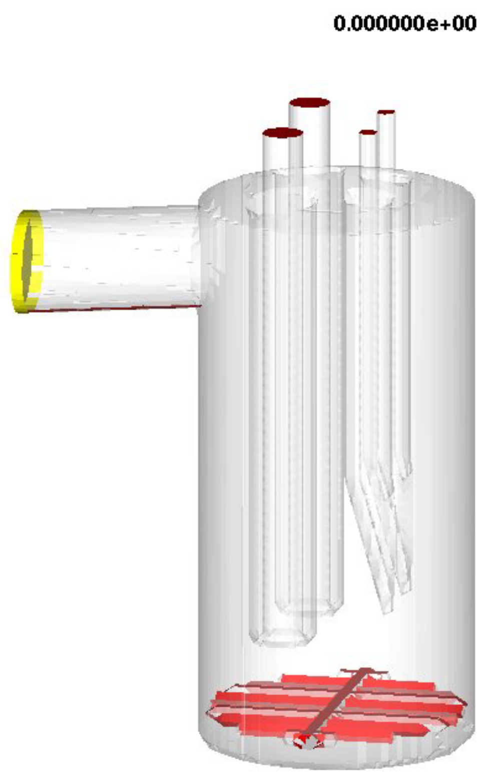

Figure 4
Standpipe configuration in a fluidized seal pot

This representation shows a typical seal pot when it is empty. Four drop legs from cyclones act as standpipes in a fluidized bed. The fluidizing gas used, be it air or steam, is introduced at the bottom of the vessel, and along the bottom of the overflow pipe.

Barracuda has been used to size the standpipes, the overflow, and the sparging rate of the fluidizing gas for both the vessel and the overflow pipe.

Scaleup

Battelle started with a 1 ton pilot plant in the early 1980's, which was scaled up to a 10 ton per day pilot plant in the late 1980's. The Burlington plant was sized for 200 dry tons per day, but was able to run at over 400 dry tons per day. It was limited by the feed system, and may have been able to run at much higher rates.

There is no need to oversize a scaleup of the Burlington plant to 1,000 tons per day or larger with the modern simulation tools we now have available. Better understanding of the circulation flow patterns, pyrolysis reaction kinetics, and fluidization criteria allow for significantly better understanding of how to design these plants economically and accurately.

For example, the entrained flow patterns inside a 6" diameter reactor are far different than what one sees in a 56' diameter reactor, primarily due to Reynolds number differences. Residence times for reacting solids thus are very different.

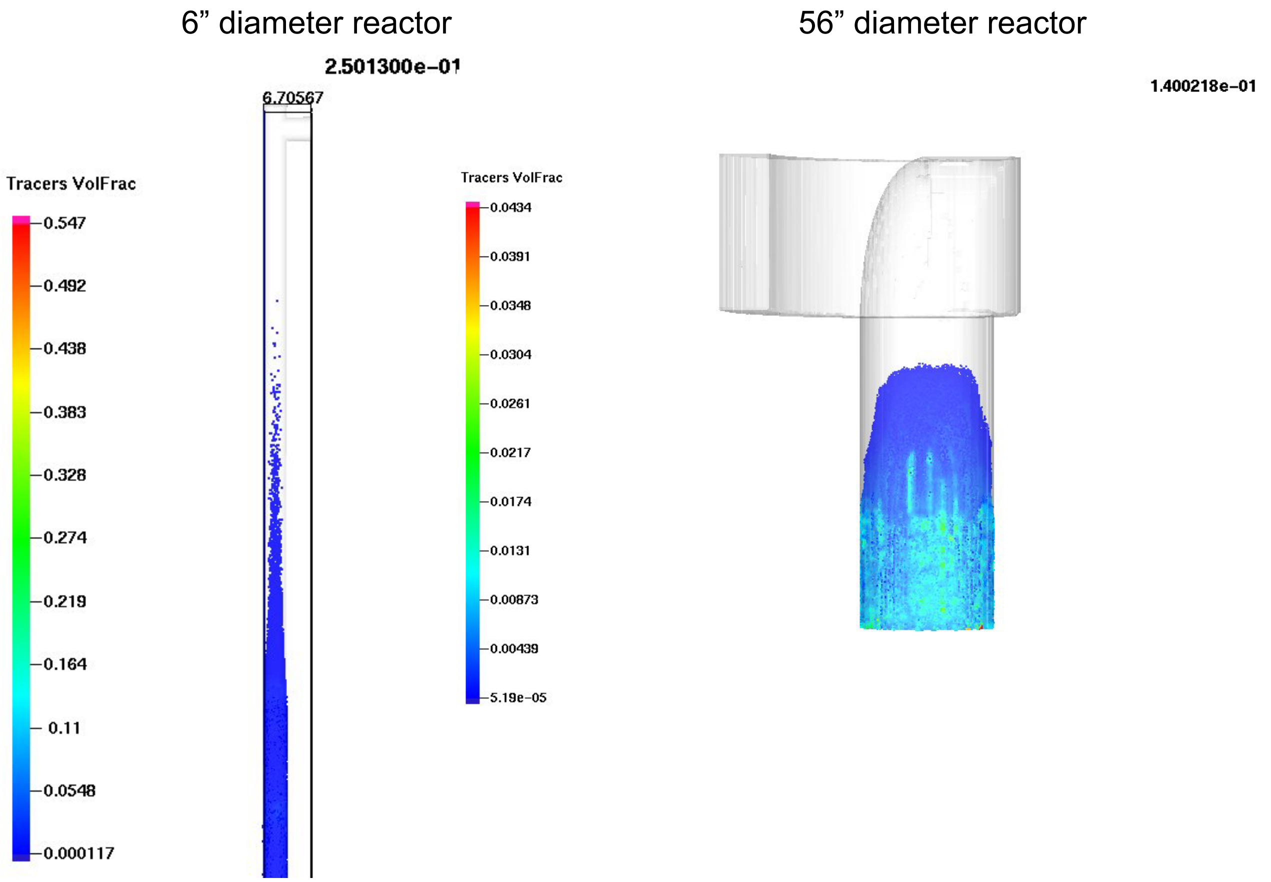

Figure 5
Reynolds and Froude number effects on scaleup of solids flows in vertical pyrolysis gasifiers

This results in limitations on the dependable accuracy of any scaleup factor one might develop from a 6” diameter reactor. In fact, the situation becomes even more different when one begins to look at the downward-flowing solids which occur along the walls of the larger vessel, that do not occur with the smaller vessel.

The problem becomes even more dissimilar, when one considers that business economics drive feedstocks to be used at as large a unit piece as possible, to reduce hogging, grinding and screening costs. How do you model a +2” piece of wood accurately in a 6” diameter reactor? Can 1/16” diameter feedstock particles for a pilot plant yield good scaleup information for a six foot diameter gasifier? The above suggest no, and SilvaGas’ experience at Burlington confirms this. Barracuda has offered SilvaGas another route to accurate answers.

Barracuda offers the capability to define the residence time of particles in the system, which facilitates more accurate evaluation of pyrolysis kinetics.

Future Work

Enhancements to the Barracuda software currently in the works include the inclusion of reaction kinetics. Another is the time-dependent size reduction of particles as they react and are consumed.

These sorts of enhancements offer the potential to significantly reduce the early iteration overdesign built into biomass pyrolysis plants such as the SilvaGas process, which should eventually reduce their capital costs significantly. In the 18 months Barracuda has been currently used, SilvaGas has identified capital cost savings of at least $ 1-2 MM in our plants that can be directly attributed to the use of Barracuda. Further work with Barracuda is anticipated to offer even more savings. We figure right now that every dollar spent on Barracuda has saved us $100 in project costs.