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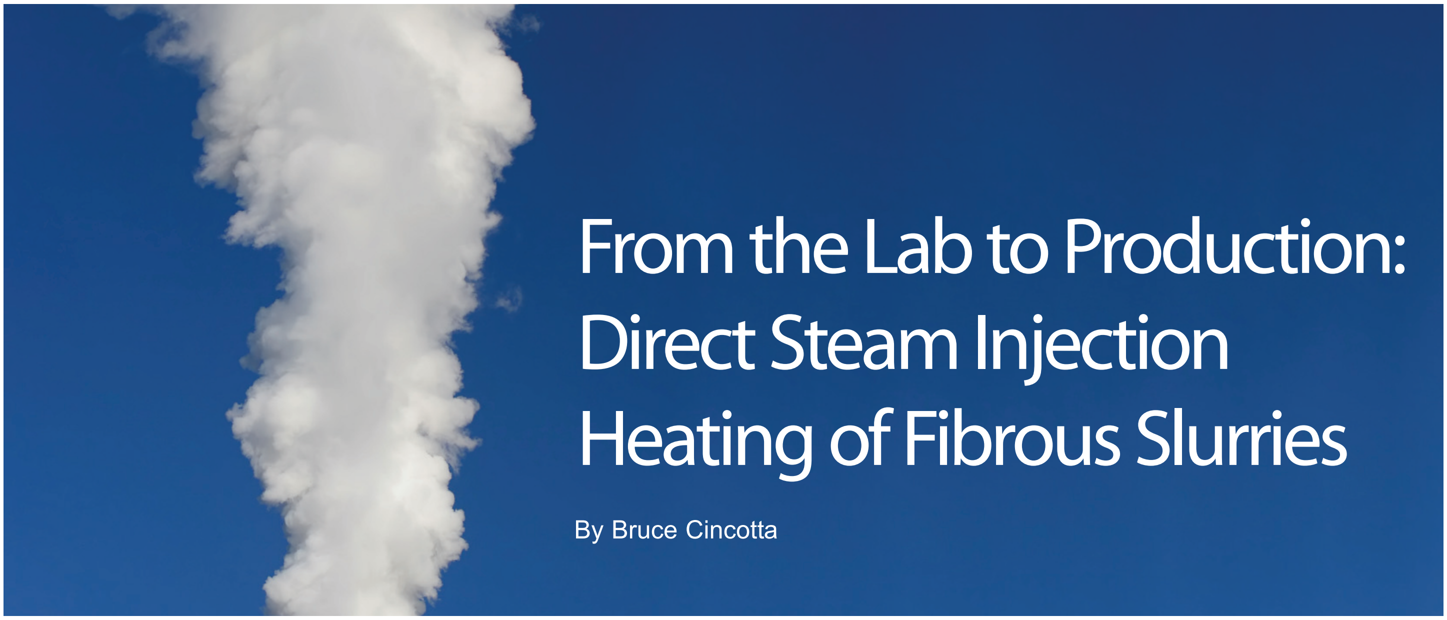

From the Lab to Production: Direct Steam Injection Heating of Fibrous Slurries

By Bruce Cincotta

The past five years have witnessed an explosion in the laboratory effort put into finding an economical way to develop pretreatment processes for biomass feedstocks in order to prepare them for conversion to sugar and ethanol. The next step requires taking that base of laboratory knowledge and converting it to on line processes. Because of the high temperatures and high desired-solids levels required for most pretreatment techniques, direct steam injection is the most practical approach to heating the slurry. The following introduces the challenges associated with scaling the lab pretreatment process to production levels, and some practical advantages of developing successful pilot strategies.

All structural plant matter is a combination of cellulose, hemicellulose and lignin. Only the direct cellulose is readily convertible to fermentable products. Hemicellulose must be converted to a fermentable form of sugar, and the lignin is generally not convertible and must be removed. Cellulose is the part of the carbohydrate portion of plants such as grass, corn stover, straw and trees. Like conventional starch conversion to ethanol, hemicellulosic materials can be converted to sugars and fermented to create ethanol, biodiesel or other useful energy products.

The Process

In all biomass processing cases, the main technological problem is to free the cellulose material in the plant to allow it to be converted without significantly reducing the yield of the existing cellulose material. This process is generally referred to as "pretreatment" of the biomass.

In the pretreatment step, a slurry of feedstock is treated with heat, time and some type of chemical to convert the hemicellulose to a sugar. Pretreatment could also be used to change the nature of the hemicellulose in order to allow a secondary agent, such as an enzyme, to hydrolyze the cellulose. This step is conducted in either a batch or continuous process. In the batch process, high-solids (20 percent to 25 percent) slurry of feedstock, usually corn stover, is fed to a high temperature reactor and subjected to high temperature (more than 300 degrees Fahrenheit). A strong chemical such as sulfuric acid, caustic or a solvent may also be present in the reactor. At the conclusion of the pretreatment step an acid or enzyme is added to hydrolyze the cellulose and form sugars. These sugars are then further processed and fermented to create ethanol.

The continuous process is another approach to pretreatment taking a pump-able slurry of feedstock and subjecting it to heat and time to soften the hemicellulosic structure. The softened slurry is then treated with acid or alkaline to break down the slurry to a form that can be hydrolyzed with an enzyme to form sugars. This process would be in-line as opposed to batch.

Transition from Lab to Production

Most of the current biomass research work has focused on laboratory techniques to determine the effects of temperature and pH (among others) on the conversion rates. These lab settings resemble the chemistry labs one might have experienced in high school and college. Pretreatment laboratory work is almost exclusively batch-driven given the complexities involved in controlling low flow processes. As a result, there is a general lack of knowledge in the best approaches and potential problems with continuous heating of the biomass feedstock stream during pretreatment in a production process.

Factors to consider when scaling up the lab process include:

- Flow rates will increase and add complexity to fluid transfer
- Residence times will change from a relatively fixed-hold vessel to a continuous flow
- The flowability of the slurry is an important factor
- Piping design and flow dynamics can add and/or change fluid velocities and impact the slurry flow.

Pilot Scale Considerations

As with all new process development, technologies need to evolve from the lab stage to production-level processes. This is a significant leap as there is more focus on the chemistry than the mechanical process in most lab settings. The goal is to develop production-level processes that maintain the unique design technology and can be scaled to reach economically feasible production-level processes. For most transitions, a pilot plant stage allows companies to test out actual process components such as conveyors, heat transfer, mixers and pumps.

Considerations for developing a pilot plant include:

- Design to mimic full scale process layouts
- Use equipment similar to full scale processes
- Be careful on the compromises from full scale
- Determine what you are trying to learn
- Make sure production-level equipment exists similar to pilot scale.

Unlike grain mash ethanol, there are significant differences in the pretreatment of corn stover, switchgrass and wood fiber. Challenges associated with fiber slurry heating include:

- Heat exchangers are generally not viable because of processing temps of 300 degrees Fahrenheit or greater
- Mixing of steam and fiber is challenging
- Consistencies greater than 14 percent create potential pumping issues
- Fluid behaves as a pseudo-plastic fluid, limiting mixing in the pipe.

The Advantages of Direct Steam Injection

Direct steam injection has a long track record in challenging slurry heating applications. Steam is readily available and can be inexpensive to produce. Scaling from small to large flows with steam is effective and reliable. Steam can also assist with producing sterile conditions. A number of methods of direct steam injection can be considered.

Spargers, fixed eductors and Venturi-style direct steam injection units generally use a fixed nozzle to inject steam. Steam control is attempted via an externally modulated steam control valve. With an externally modulated steam injector, the steam pressure is adjusted to control the flow rate of steam with a control valve. The use of external steam control devices to control the steam flow by modulating the steam pressure can lead to excessive steam hammer and vibration. Steam hammer and vibration often result from poor mixing and condensing of the steam. As temperature demand drops, steam pressure drops, lowering the steam velocity and potentially causing instability. Uncondensed steam bubbles will typically collapse when they come in contact with a cold pipe wall in the liquid piping. When these bubbles collapse, the slurry rushes in to fill the void and impacts the pipe wall. In some cases this will result in some pinging noise and, in severe cases, steam hammer and vibration.

Reactor vessels for batch processing are capable of high solids percentage consistencies. They are flexible for hold time, temperature and pressure changes. Reactor heating can also be energy efficient with minimal water usage. Challenges with reactor heating include limitations associated with scaling up for production and their ability to be integrated with continuous production strategies. Reactor heating vessels also have high equipment costs associated with them.

Inline direct steam injection is well suited for continuous fiber slurry heating processes. Inline direct steam injection heaters are capable of high temperature rise and can be arranged in a multistage layout to allow for precise temperature control and smooth operation. Inline direct steam injection heaters have a low pressure drop across the heater which minimizes energy demand on the slurry pumps and limits flow disruptions to the slurry.

Keys to Successful Direct Steam Injection

One of the key factors to successful direct steam injection is maintaining high steam velocity for effective mixing and condensation of the steam into the fiber slurry. Internal modulation allows steam to be injected at sonic velocity to achieve choked flow. Choked flow is the phenomenon of accelerating a vapor to sonic velocity by creating a pressure differential through an engineered nozzle. By establishing choked flow, the steam mass flow can be metered to precisely control the heating of the slurry. This produces predictable results based on position of the stem plug. Through a variable-area steam diffuser, steam flow is metered at the point where steam and liquid first contact and mix. This method eliminates the need for an external steam control valve or downstream mechanical mixing devices. Other features include:

- High velocity steam is essential (1,000 feet per second is ideal)
- Process and steam pressure differential are required
- Steam jet characteristics are critical to disperse steam and avoid hot spots
- Proper sizing is important
- Mechanical mixers to blend steam are not practical

Steam injection transfers a tremendous amount of energy and needs to be applied properly for successful results.

Process, Equipment Design Considerations

When designing a pilot plant or scaling up for production-level processing, several factors should be considered when integrating direct steam injection for the pretreatment process. Avoid large, single point steam additions and ensure a means for even steam distribution. Design the pumping and piping process to promote steady and stable slurry flow. Be aware of the pH environment and the potential for corrosion. Abrasives can be present depending on the feedstock, and particulates can be present from the biomass collection process. Some consideration needs to be given to proper screening and separation techniques. Preheating of water may be a practical way to reduce the steam and water demand.

Developing a successful pretreatment strategy is obtainable and can be achieved by using available planning and utilization resources. The integration of heat into the pretreatment plant design can be done reliably and with predictable results. The processing of fibrous slurries has a long history in the pulp and paper industry with process fiber flow resources available through organizations such as the Technical Association of the Pulp and Paper Industry. Remember that a well thought out pilot plant plan is essential for identifying and resolving potential bottlenecks in the process. Once the production plant is operational, the pilot plant can continue to pay off by allowing for optimization of process design off line. **BIO**

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