



Moving From the Lab to Production ... Direct Steam Injection Heating of Fibrous Slurries Bruce Cincotta – ProSonix LLC

Key words: biomass, pretreatment, cellulosic, direct steam injection

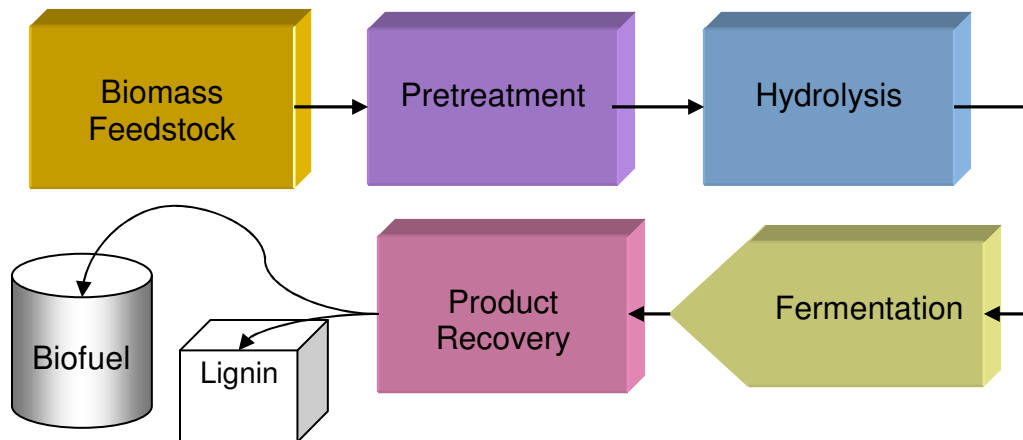
In the past five years there has been an explosion in the laboratory effort put into finding an economical way to develop pretreatment processes for biomass feedstock's, in order to prepare them for conversion to sugar and ethanol. The next step is to take that base of laboratory knowledge and convert it to online processes. Because of the very high temperatures and high desire solids levels required for most pretreatment techniques, direct steam injection is the most practical approach to heating the slurry. This paper will introduce the audience to the challenges associated with scaling their lab pretreatment process to production levels, and some practical advantages of developing successful pilot strategies.

What is Biomass?

All structural plant matter is a combination of cellulose, hemicellulose, and lignin's. Only the direct cellulose is readily convertible to fermentable products. Hemicellulose must be converted to a fermentable form of sugar and the lignin's are generally not convertible and must be removed. Cellulose is the part of the carbohydrate portion of plants such as grass, corn stover, straw, trees, etc. Like conventional starch conversion to ethanol, hemicellulosic materials can be converted to sugars and fermented to create ethanol, bio-diesel, 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, or to change the nature of the hemicellulose in order to allow a secondary agent, such as an enzyme, to hydrolyze the cellulose.

Batch Process - Here, high solids (20-25%) slurry of feedstock, usually corn stover, is fed to a high temperature reactor and subjected to high temperature (over 300°F). A strong chemical like 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.

Continuous Process - Another approach to pretreatment is to take a pumpable slurry of feedstock and subject it to heat and time to soften the hemicellulosic structure. The softened slurry is then acid or alkaline treated 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, pH, etc. on the conversion rates. These lab settings resemble the chemistry labs you may 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 your lab process:

- Flowrates will increase and add complexity to fluid transfer
- Residence times will change from relatively fixed hold vessel to a continuous flow
- The flowability of the slurry is an important factor
- Piping design & flow dynamics can add 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; however, can be scaled to reach economically feasible production level process. 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:

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

Unlike grain mash ethanol, there are significant differences in the pretreatment of corn stover, switch grass, wood fiber, etc. used. Challenges associated with fiber slurry heating:

- Heat exchangers generally not viable because of processing temps of 300 °F or higher.
- Mixing of steam and fiber is challenging
- Consistencies above 14% 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 (DSI) 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 very effective and reliable. Steam can also assist with producing sterile conditions. There are a number of methods of Direct Steam Injection that can be considered:

Spargers, Fixed Eductors & Venturi Style DSI – These units generally use a fixed nozzle to inject steam and 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 & 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 (Figure 1). 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 & vibration.

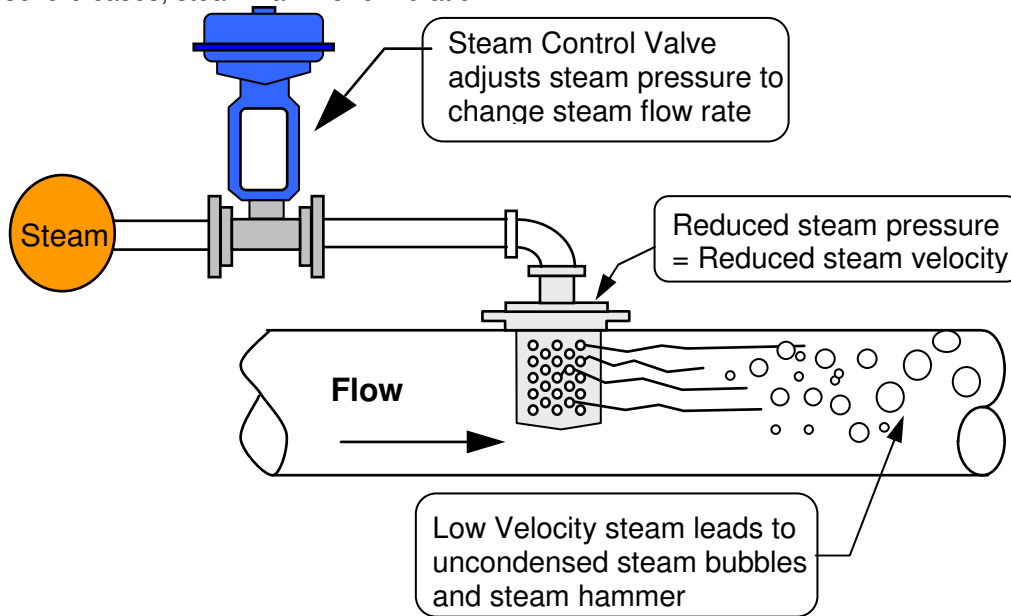
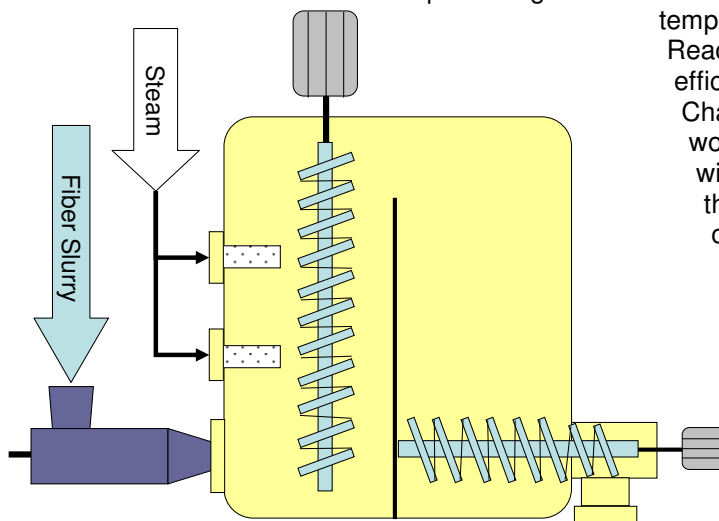


Figure 1 Steam Sparger

Reactor Heating – Reactor vessels for batch processing (Figure 2) are capable of very 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 would be 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.

Figure 2 Process reactor with steam sparger



Inline Direct Steam Injection Heating – Inline Direct Steam Injection (DSI) is a very good approach and well suited for continuous fiber slurry heating processes. Inline DSI heaters are capable of a very temperature rise and can be arranged in a multi-stage layout to allow for precise temperature control and smooth operation. Inline DSI heaters have a very low pressure drop across the heater which minimize energy demand on the slurry pumps and limit flow disruptions to the slurry.

Keys to Successful Direct Steam Injection

One of the key factors to successful DSI 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.

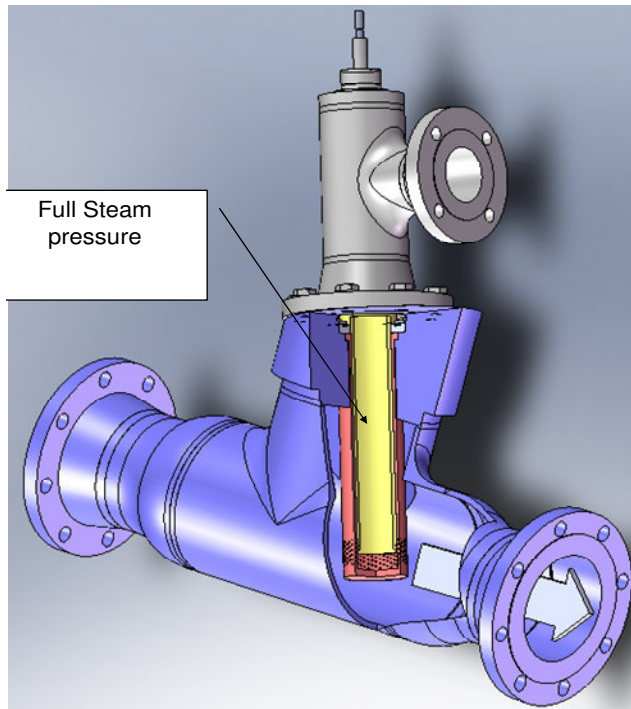


Figure 3 Inline Steam Injection Heater

- High velocity steam is essential (1,000 fps ideal)
- Requires process and steam pressure differential
- Steam jet characteristics critical to disperse steam and avoid hot spots
- Proper sizing is important
- Mechanical mixers to blend steam not practical

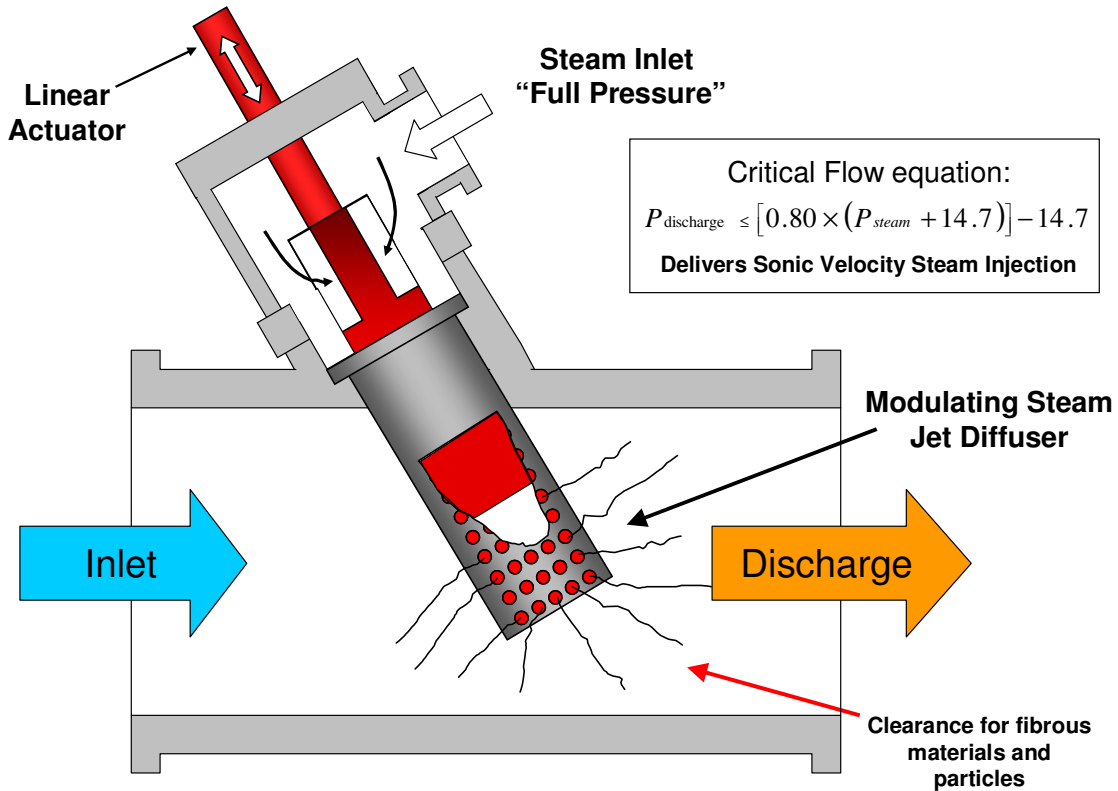


Figure 4 Inline steam process heater with internal modulation

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

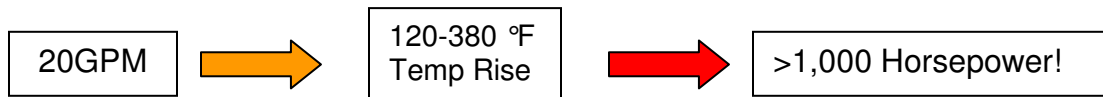


Figure 5 The Power of Steam

Process & Equipment Design Considerations

When designing your Pilot Plant or scaling up for Production level processing, there are several factors to consider when integrating Direct Steam Injection for your Pretreatment process.

- Avoid large, single point steam additions and insure a means for even steam distribution.
- Design your pumping and piping process to promote steady and stable slurry flow.
- Be aware of your Ph Environment and the potential for corrosion.
- Abrasives can be present depending on your 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.

Process Considerations

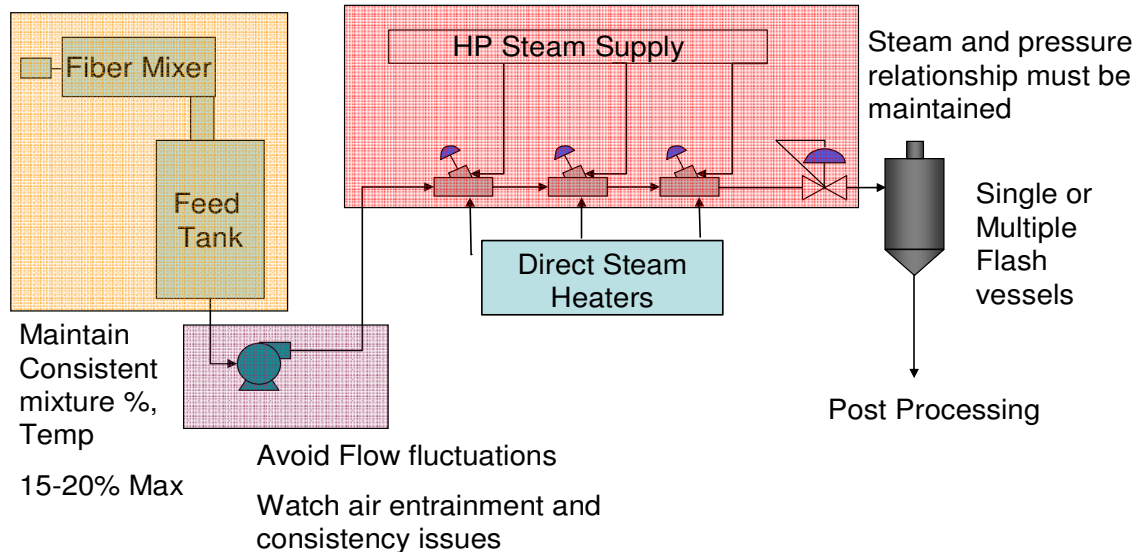


Figure 5 Inline Direct steam process heating layout

Developing a successful Pretreatment strategy is obtainable, and can be achieved by planning and utilization resources that are available. The integration of heat into your Pretreatment plant design can be done reliably and with predictable results. The processing of fibrous slurries has a long history in the Pulp & paper industry with process fiber slow resources available through organizations such as TAPPI (www.tappi.org). Remember that a well thought out Pilot Plant plan is essential for identifying and resolving potential bottlenecks in your process. Once the production plant is operational, the Pilot Plant can continue to pay off by allowing for optimization of process design off line.

*This article will be appearing in a future edition of Biomass Magazine

Bruce Cincotta *MEng*– Chief Technical Officer & Co-Owner of ProSonix LLC
 ProSonix specializes in solving difficult process heating problems through innovative products and engineering solutions. Mr. Cincotta has been in the process heating world for 20 years, working in the starch, paper, energy, and ethanol areas. He holds a MS-Engineering degree and specializes in process equipment design. He holds 6 patents for steam equipment and has presented technical papers to TAPPI, WEFTEC, FEW, and the Biomass Conference. For additional information, please visit www.pro-sonix.com, or contact ProSonix by phone at 800-849-1130 or by e-mail at info@pro-sonix.com.