NATIONAL RENEWABLE ENERGY LABORATORY
GOLDEN, COLORADO

SUBCONTRACT ACO-9-29067-01
PROCESS DESIGN AND COST ESTIMATE OF CRITICAL EQUIPMENT IN THE BIOMASS TO ETHANOL PROCESS

REPORT 99-10600/17
CONTINUOUS ACID HYDROLYSIS REACTOR

JANUARY 22, 2001
REV WEB

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1. SUMMARY

National Renewable Energy Laboratory (NREL) has requested that Harris Group Inc. (HGI) help determine the commercial pricing of the presteaming vessels and continuous acid hydrolysis reactors for three different processes. All the processes convert wood chips to sugars in high temperature, dilute sulfuric acid concentration reactors. The sugar is then converted to ethanol in the remaining process equipment. Each of the processes has different temperatures, pressures, residence times, and acid concentrations. The purpose of this report is to compare the pricing from vendor bids and recommend which bids should be used in a capital cost estimate. Also included is an installation cost for each option. Of the two vendors, HGI recommends using the Andritz quotes. Although their pricing is higher, HGI feels Andritz's experience and thoughtful approach taken to the metallurgy and physical process are the most comprehensive. On a price-per-reactor basis the Andritz bid is competitive.

Future work should include a determination of how full the reactors must be for adequate mixing and consistent cooking. The results of this study may reduce the number of reactor vessels and subsequent cost.

2. INTRODUCTION

HGI has been working with NREL to estimate pricing for the acid hydrolysis reactors for various processes. The work has involved corrosion testing to determine appropriate reactor metallurgy for the proposed process operating parameters. It has also included a vendor analysis to choose appropriate vendors for pricing the reactors (see Appendix A). Two vendors, Andritz and Anco-Eaglin, were chosen for their previous experience with acid hydrolysis and an acid hydrolysis reactor specification was sent to them. The vendors provided pricing on three different processes: Process 100, Process 200 Stage 1, and Process 300 Stages 1 and 2. This report summarizes the information and pricing supplied by the vendors and respective installation costs.

3. DESCRIPTION

3.1 Process Summaries

NREL under the direction of the Office of Fuels Development at the U.S. Department of Energy has, over the years, developed a process for converting cellulosic biomass to fuel ethanol based on NREL and subcontracted research and standard engineering practices. Three specific variations of the process were considered for the work in this subcontract:

- Pretreatment with Enzymatic Hydrolysis (P100)
- Two-Stage Countercurrent Acid Hydrolysis (P200)
- Two-Stage Dilute Acid Hydrolysis (P300)

In Process 100, biomass feedstock in chip form is introduced to the plant and screened. . The chips are passed to a scalper screen to remove very large materials, then onto a chip thickness sizing screen. We assume that approximately 20% of the incoming material will be oversized and will require processing through a single-disc refiner system. The disc refiner reduces oversized material to less than 19 mm, suitable for the pretreatment reactors. The biomass is pretreated to make it more susceptible to acid penetration. During pretreatment, much of the hemicellulosic portion of the biomass is hydrolyzed into soluble sugars in a continuous hydrolysis reactor. This reactor uses steam and dilute sulfuric acid to initiate hydrolysis. Afterwards, the liquid portion of the pretreated slurry must be separated from the solids to facilitate conditioning of the liquid portion to remove compounds, such as acetic acid, that may be toxic to downstream fermentative organisms. Once the liquid stream is conditioned properly (most likely via ion exchange and overliming), it is recombined with the solids and sent to fermentation.

This process uses simultaneous saccharification and cofermentation (SSCF) to hydrolyze cellulose and ferment the resulting glucose and other sugars present to ethanol in the same vessel. As this design currently stands, a portion of the pretreated hydrolyzate is drawn off and used to produce cellulase enzyme. The enzyme is then added to the fermentation vessels. A recombinant ethanologen is used to ferment multiple sugars to ethanol. The resulting beer is then sent to distillation and dehydration to purify and concentrate the ethanol. The lignin portion of the original biomass gets carried through the system and exits with the distillation bottoms. This lignin is used as fuel for the burner/boiler system in the plant. As a result it must be dewatered sufficiently to achieve proper combustion.

Process 200 uses no acid in the first stage and a countercurrent reactor design in the second stage of hydrolysis to convert the hemicellulose and a large portion of the cellulose in the biomass to soluble sugars. The second-stage reactor separates the solids and liquor containing dissolved sugars. The solids are sent to the boiler and the liquid is sent to the oligomeric reactor and flash tank. The liquor is then neutralized and sent to fermentation. The back end of the process is the same as Process 100, but the process stream is liquid only.

Process 300 differs from Process 100 in that no enzymes are used. All hydrolysis is accomplished thermochemically. In the first stage of hydrolysis, the hemicellulosic portion of the biomass is hydrolyzed to soluble sugars. These sugars must then be washed from the slurry prior to the second stage of hydrolysis or else they will be degraded at the more severe conditions. The soluble sugar stream is neutralized (with stoichiometric amounts of lime) and sent to fermentation. The solids stream, primarily cellulose and lignin, is sent to the second stage of hydrolysis to further hydrolyze cellulose to glucose. After hydrolysis this stream is also sent to fermentation. The back end of the process is the same as Process 100.

A comparison of the differences in the presteaming and reactor operating conditions can be found in Table 1.

Table 1
Process Conditions

Description	Unit	Conditions
WOOD CHIP TYPES		yellow poplar, Douglas fir, or ponderosa pine
Average size	in.	3.4 x 3.4 x 1.4 in.
Feed stock rate	metric tpd	2000
Average wood density	g/ml	1.217
Moisture	%	47.9
Bulk density	lb/cu ft	8-10
PROCESS 100		
Process Flow Diagram	Revision E	PFD-P100-A201
Equipment Number		M –202
Chip Presteamer Vessel		
Operating temperature	^oC	100
Operating pressure	atm	1
Steam pressure	atm	4.42
Steam flow	kg/hr	17,115
Residence time	minutes	20
Chip flow into vessel	kg/hr	159,948
Metallurgy		316 L SS
Hydrolysis Reactor		
Operating temperature	^oC	180
Operating pressure	atm	9.75
Acid concentration (% liquid)	%	0.7
Acid flow (2.133% sulfuric)	kg/hr	60,521
Steam pressure	atm	13
Steam flow	kg/hr	32,638
Reactor residence time	minutes	10
Total flow from reactor	kg/hr	271,313
Metallurgy		Alloy 825
PROCESS 200 STAGE 1		
Process Flow Diagram	Revision A	PFD-P202-A201
Equipment Number		M-202

Table 1
Process Conditions (continued)

Description	Unit	Conditions
Chip Presteamer Vessel		
Operating temperature	°C	100
Operating pressure	atm	1
Steam pressure	atm	4.42
Steam flow	kg/hr	10,929
Residence time	minutes	20
Chip flow into vessel	kg/hr	159,948
Metallurgy		316 L SS
Hydrolysis Reactor		
Acid concentration	%	0
Operating temperature	°C	183
Operating pressure	atm	10.5
Steam pressure	atm	25
Steam flow	kg/hr	10,929
Water flow	kg/hr	76,679
Reactor residence time	minutes	9
Total flow from reactor	kg/hr	277,931
Metallurgy		316 L SS
PROCESS 300 STAGE 1		
Process Flow Diagram	Revision E	PFD- P300-A201
Equipment Number		M-201
Chip Presteamer Vessel		
Operating temperature	°C	100
Operating pressure	atm	1
Steam pressure	atm	4.42
Low pressure steam flow	kg/hr	16,967
Chip flow into vessel	kg/hr	159,948
Residence time	minutes	20
Metallurgy		316 L SS

Table 1
Process Conditions (continued)

Description	Unit	Conditions
Hydrolysis Reactor		
Operating temperature	°C	190
Operating pressure	atm	12.12
Acid concentration (% liquid)	%	0.5
Acid flow (1.9 % sulfuric)	kg/hr	48,495
Steam pressure	atm	13
Steam flow	kg/hr	44,617
Reactor residence time	minutes	4
Total flow out of the reactor	kg/hr	270,027
Metallurgy		Alloy 825
PROCESS 300 STAGE 2		
Process Flow Diagram	Revision E	PFD-P300-A204
Equipment Number		R-202
Chip Presteamer Vessel		
Operating temperature	°C	100
Operating pressure	atm	1
Acid concentration (% liquid)	%	0.03
Feed flow to presteamer	kg/hr	123,032
Feed (% insoluble solids)	%	45.6
Steam pressure	atm	4.42
Steam flow	kg/hr	5,811
Residence time	minutes	20
Metallurgy		317L SS
Hydrolysis Reactor		
Operating temperature	°C	210
Operating pressure	atm	18.39
Acid concentration (% liquid)	%	1.7
Acid flow (20% sulfuric)	kg/hr	8,476
Steam pressure	atm	23
Steam flow	kg/hr	25,053
Total flow out of reactor	kg/hr	162,372
Reactor residence time	minutes	3
Metallurgy		zirconium clad

3.2 Vendor Equipment

Andritz's industrial background is in the pulp and paper industry. Anco-Eaglin's industrial experience is with animal rendering and acid hydrolysis of chicken feathers. They both took approaches to the acid hydrolysis based on their experience. The results of their approaches led to fairly large disparities in the bids they provided. Both vendors suggested horizontal reactor vessels. Material in the reactors is moved through the reactor by internal paddles or screws.

3.2.1 Andritz

The equipment trains proposed by Andritz largely consisted of a presteaming bin, integral metering conveyor, chute, plug screw feeder, and horizontal reactor(s) (digesters) with an internal screw and blowback valve. The plug screw feeder was used between equipment to increase the pressure of the feedstock to the reactor vessel. A blowback valve is used as material is blown out of the reactor to prevent loss in vessel pressure. Integral instruments were included. Chesterton mechanical seals and motors were included. No structural support, ladders, or catwalks were included in the pricing. All the major equipment provided has been used in the pulp and paper industry. The same size of reactor was provided for each process with the numbers of reactors and reactor trains changing with different residence times. For longer residence times there were two reactors back to back per train. Metallurgy changed according to the process conditions (see Appendix B).

3.2.2 Anco-Eaglin

The equipment trains provided by Anco-Eaglin were basically the same except for the metallurgy required for the different processes. Differences in residence time between the processes were considered with smaller reactors.

The presteamer is fed by a set of screw conveyors with variable frequency drives to adjust and vary the feed as the process may dictate. The presteamer is a horizontal vessel with a paddle type device within to move the chips. The discharge from the presteamer is a variable-frequency screw conveyor leading to a blow tank. The blow tank was used to act as a seal between the presteamer and the reactor. The blow tank has a live bottom screw to feed the material to the reactor. The live bottom with multiple tightly flighted screws feeds into a pipe. Steam is injected into the screw to pressurize it on the way to the reactor. Anco described the steam injection as a venturi-like arrangement. The steam acts as a motive force to pull the chips into the reactor. They have done this with powders, but have no experience with materials similar to wood chips. The blow tank will be supplied with a relief valve. In Anco-Eaglin's experience with other materials, a plug is formed in the screw and this keeps the difference in pressure between vessels. The reactor vessel also has a paddle-type device within to keep the material flowing through it. The pitched flight reactor discharge conveyors are also variable-frequency drive. Anco-Eaglin felt that the close pitched flights would allow the material to act as a seal coming out of the vessel. (In other designs they have blown the material into a flash chamber or blow pot with a 4-in. gate valve that opens and closes with pressure.) Integral instrumentation, oil-cooling system, and motors were provided. High-pressure stuffing boxes, multiple packing rings, lantern rings, and water flush sealing were used to minimize leakage. Any leakage would be carried into the vessel rather than into the atmosphere. (NREL confirmed that this would not be a problem.) Catwalks, presteamer support steel, and handrails are provided. HGI has reservations as to how the Anco-Eaglin design gets up to pressure in the reactor and how pressure is sealed between the stages.

4. DISCUSSION

The results of the bids for the presteamer and reactor vessel packages for each process are listed in Table 2. There are substantial disparities in price between Andritz and Anco-Eaglin for the same process operating conditions. Breaking the information down further helps clarify the differences. The largest single contributor to the price difference was the assumption of percent full volume in the reactor vessels. In horizontal pulping digesters, Andritz has historically used 40% to 50% full for the chip level. Andritz' experience has indicated that the chips flow better and there is a more even distribution of acid and steam. HGI's experience has indicated that the chips can flow backwards over the top of the reactor screw if the level is too high. The result can be uneven cooking. Other digester (pulping reactor) vendors use as high as 75% full for horizontal vessels. Andritz used the same basic reactor size, varying the number of reactors and trains for the residence time required.

Anco-Eaglin has designed the reactor vessels for 95% full at 10 minutes of residence time (see Table 3). Anco's experience with materials other than chips is that a full vessel is adequate for proper mixing and cooking. The Anco design includes a paddle arrangement to keep a plug moving rather than a screw. Anco has not experienced quality problems from materials flowing backwards.

Please note that the same density was used for Stage 1 and Stage 2 of Process 300 for both vendor quotes. A difference in the Process 300 Stage 2 density would affect the reactor volume.

In Table 2 the total horsepower is listed for each of the processes. The Andritz equipment is nearly double the required horsepower of the Anco-Eaglin quote. The plug screw feeders used in the Andritz design are the reason for this difference. The plug screw feeders range between 600 and 700 hp. The pressure for the next stage is created in the plug screw feeder. This is consistent with pulp and paper industry experience. Note that Process 300 Stages 1 and 2 have lower individual horsepowers due to the reduced number of trains. The main horsepower consumption in the Anco-Eaglin quote is in the presteamer and reactor paddles. The paddles are used to move a solid plug of the feedstock from one end of the vessel to the other. Each of the paddles has a motor estimated at 250 hp. In contrast, the screws in the Andritz quote require 25 hp at partial loading.

The metallurgy for the reactors is the same for all the quotes. The associated equipment varies in its metallurgy. Andritz took greater care in keeping the metallurgy exposed to severe process conditions consistent. If the reactor required Alloy 825, the reactor screw in and the plug screw feeder housing were also clad in the same metallurgy. For the zirconium-clad vessel in Process 300 Stage 2, Andritz provided alternative pricing for a 316L stainless steel screw. It may be cost effective to keep replacing this equipment as it corrodes rather than paying the price for the metallurgy. (Both prices are found in Table 3.) Anco-Eaglin did not provide in-kind metallurgy for equipment that would be exposed to the reactor conditions. More corrosion testing would be required to make a risk assessment for lesser metallurgies.

Table 2
Vendor Quote Comparison

Process	Vendor	Equipment Price	Trains	Presteamer	Reactor	Presteamer Feeder	Reactor Feeder	Reactor Discharge	Seals	Valves	Miscellaneous	Horsepower
Process 100 -- 10 minute residence time	Ancho Eaglin		Three	(3) horizontal 316L SS presteaming bins 11'Dx26'TT 75.9 cuM each, 227.6 cuM total volume. 316L SS rotator & Paddle	(3) horizontal Alloy 825 reactors 8'Dx26'TT 38.9 cuM each, 116.7 cuM total volume, 316LSS rotator & paddle	(3) 24" 316LSS Screw	(3) 24" 316L SS Screw w/ headbox and gear box	24" 316LSS Screw	High pressure stuffing boxes, multiple packing rings, lantern rings and water flush sealing	PRV's, PSV's, Steam Control valves, Reactor Blow Valves	316L SS Blow Tank w/ live bottom, Instruments, Catwalks, structural steel for Presteamer Oil cooling system	1741 HP
	Andritz		Five	(5) 316L SS presteaming bins, 85% fill, 50 cuM each, 250 cuM total	(10) horizontal Alloy 825 reactors 72"Dx 45'-10"TT, 36.7 cuM each, 367cuM total, w/ Alloy 825 screw		(5 each) 316L SS twin agitator feeder, Plug Screw Feeder w/ ALLoy 825 Housing		Chesterton special Mechanical w/lubrication system	(5) Alloy 825 Blow Back Valve	Instruments, motors, gear boxes	3512.5 HP
Process 200 Stage 1 -- 9 minute residence time	Ancho Eaglin		Three	(3) horizontal 316L SS presteaming bins 11'Dx26'TT 75.9 cuM each, 227.6 cuM total volume. 316L SS rotator & Paddle	(3) horizontal 316L SS reactors 8'Dx26'TT 38.9 cuM each, 116.7 cuM total volume, 316LSS rotator & paddle	(3) 24" 316LSS Screw	(3) 24" 316L SS Screw w/ headbox and gear box	(3) 24" 316LSS Screw	High pressure stuffing boxes, multiple packing rings, lantern rings and water flush sealing	PRV's, PSV's, Steam Control valves, Reactor Blow Valves	316L SS Blow Tank w/ live bottom, Instruments, Catwalks, structural steel for Presteamer Oil cooling system	1741 HP
	Andritz		Five	(5) 316L SS presteaming bins, 85% fill, 50 cuM each, 250 cuM total	(10) horizontal 316L SS reactors 72"Dx 45'-10"TT, 36.7 cuM each, 367cuM total, w/ 316L SS screw		(5 each) 316L SS twin agitator feeder, 316L SS Plug Screw Feeder		Chesterton special Mechanical w/lubrication system	(5) 316L SS Blow Back Valve	Instruments, motors, gear boxes	3512.5 HP
Process 300 Stage 1 -- 4 minute residence time	Ancho Eaglin		Three	(3) horizontal 316L SS presteaming bins 11'Dx26'TT 75.9 cuM each, 227.6 cuM total volume. 316L SS rotator & Paddle	(3) horizontal Alloy 825 SS reactors 5'Dx26'TT 15.2 cuM each, 45.6 cuM total volume, 316LSS rotator & paddle	(3) 24" 316LSS Screw	(3) 24" 316L SS Screw w/ headbox and gear box	(3) 24" 316LSS Screw	High pressure stuffing boxes, multiple packing rings, lantern rings and water flush sealing	PRV's, PSV's, Steam Control valves, Reactor Blow Valves	316L SS Blow Tank w/ live bottom, Instruments, Catwalks, structural steel for Presteamer Oil cooling system	1741 HP
	Andritz		Four	(4) 316L SS presteaming bins, 85% fill, 70 cuM each, 280 cuM total	(4) horizontal Alloy 825 reactors 72"Dx 45'-10"TT, 36.7 cuM each, 367cuM total, w/ Alloy 825 screw		(4 each) 316L SS twin agitator feeder, Plug Screw Feeder w/ ALLoy 825 Housing		Chesterton special Mechanical w/lubrication system	(4) Alloy 825 Blow Back Valve	Instruments, motors, gear boxes	3170 HP
Process 300 Stage 2 -- 3 minute residence time	Ancho Eaglin		Three	(3) horizontal 317L SS presteaming bins 11'Dx26'TT 75.9 cuM each, 227.6 cuM total volume. 317L SS rotator & 316L SS Paddles	(3) horizontal Zirconium Clad SS reactors 5'Dx26'TT 15.2 cuM each, 45.6 cuM total volume, 317LSS rotator &316L SS paddles	(3) 24" 316LSS Screw	(3) 24" 316L SS Screw w/ headbox and gear box	(3) 24" 316LSS Screw	High pressure stuffing boxes, multiple packing rings, lantern rings and water flush sealing	PRV's, PSV's, Steam Control valves, Reactor Blow Valves	316L SS Blow Tank w/ live bottom, Instruments, Catwalks, structural steel for Presteamer Oil cooling system	1741 HP
	Andritz		Four	(4) 317L SS presteaming bins, 85% fill, 70 cuM each, 280 cuM total	(4) horizontal Zirconium clad 72"Dx 45'-10"TT, 36.7 cuM each,146. 8 cuM total, w/ zirconium Clad screw		(4 each) 317L SS twin agitator feeder, Plug Screw Feeder w/ 317L SS Housing		Chesterton special Mechanical w/lubrication system	(4) 317L SS Blow Back Valve	Instruments, motors, gear boxes	3170 HP

Table 3
Vendor Pricing Comparison Based on Similar Assumptions

Vendor	Process	Equipment Price/Reactor (million $)	Metallurgy	% Full	Number of Reactors
Anco-Eaglin	100		Alloy 825 w/316L paddles	95%	3
Andritz	(10 minutes)		Alloy 825 w/825 screw	40% to 50%	10
Anco-Eaglin	200 Stage 2		316L SS	85.5%	3
Andritz	(9 minutes)		316L SS	40% to 50%	10
Anco-Eaglin	300 Stage 1		Alloy 825 w/316 paddles	95%	3
Andritz	(4 minutes)		Alloy 825 w/825 screw	40% to 50%	4
Anco-Eaglin	300 Stage 2		Zirconium-clad reactor w/316 paddles	95%	3
Andritz	(3 minutes)		Zirconium-clad reactor w/ zirconium-clad screw w/ 316 screw	40% to 50%	4

Comparing the price per reactor for each process with other sundry equipment equally divided, the digester prices are more in line with each other. Note that the differences in price per reactor decreases as the number of digesters approach each other. The reason for this is twofold: (1) The engineering is divided between the same number of reactors. (2) The associated equipment is distributed differently. For example in the Andritz quotes, Process 100 and Process 300 Stage 1 have the same metallurgy. One would assume that the price per reactor would be close to the same for the Andritz quotes. This is not the case. The reason is that the trains in Process 100 contain two piggybacked reactors with one plug screw feeder and the Process 300 train has one plug screw feeder for each reactor. The plug screw feeders are an expensive piece of equipment because they are Alloy 825 clad. An additional difference for the Process 300 reactors is a higher design pressure. This makes the vessel more expensive as well.

In terms of metallurgy, the cost factor between Alloy 825 and 316L stainless steel ranges from a factor of 1.19 to 1.3 per reactor. (These factors were derived from Table 3 for Anco-Eaglin 2.36/ 1.98 = 1.19 and for Andritz 1.633/1.266 = 1.3.) The cost factor between zirconium clad and 316L stainless steel ranges by a factor of 1.75 to 1.81 per reactor. (See corrosion study, Appendix B.)

4.1 Installation Pricing

The installed cost factor for Process 200 Stage 1 was based on HGI experience on a previous job with similar operating conditions and 316L stainless steel piping (see Table 4). Installation costs for the Andritz and Anco-Eaglin equipment were based on the respective equipment costs. The other installed cost options were adjusted to reflect the differences from the Process 200 Stage 1 equipment. For example, most of the equipment involves 316L stainless steel piping. There should be no difference between the process stages for the piping if the throughput, piping, and pieces of equipment are the same. Therefore, the same installed piping cost should be used. Installation does not include engineering, contingency, field engineering, or start-up.

Table 4
Reactor Equipment and Installed Cost

	Andritz			Anco-Eaglin		
Process	**Equipment Price**	**Total Installed Cost**	**Installed Direct Cost Factor**	**Equipment Price**	**Total Installed Cost**	**Installed Direct Cost Factor**
Process 100		$35,856,000			$16,249,000	
Process 200 Stage 1		$32,190,000			$15,101,000	
Process 300 Stage 1		$24,698,000			$15,959,000	
Process 300 Stage 2		$33,514,000			$21,907,000	

For the Andritz pricing, Processes 100 and 200 contain five trains. Both contain 316L stainless steel piping. The difference in metallurgy between Process 100 and Process 200 Stage 1 is reflected in the equipment pricing. Process 300 Stage 1 also has 316L stainless steel piping. However, Process 300 Stages 1 and 2 both have four trains. The installed cost for Process 300 was factored down for four stages. The piping metallurgy for Process 300 Stage 2 reflects 317L stainless steel. So, the installation costs of the piping increased for this option over Process 300 Stage 1. (The details for installation pricing can be found in

Appendix C.) Installed costs for Andritz include catwalks and handrails, etc., This is reflected in the higher equipment installation dollars for Andritz (see Appendix C).

The installation costs for the Anco-Eaglin quote are the same for Stage 1 of the process options. All three have 316L stainless steel piping. For all the Anco-Eaglin options the number of trains is the same and the throughput is the same even though the reactor sizes vary somewhat. Therefore, other than metallurgy changes the installation costs are very similar. Process 300 Stage 2 installation cost reflects 317L stainless steel piping.

Because Andritz paid more attention to keeping the metallurgy consistent with the agitators and feed screws, HGI believes that the Andritz quotes are a better indication of the differences between the different types of process. Note that Process 200 Stage 1 is basically a metallurgy of 316L stainless steel. There are five trains in the Andritz quote for the residence time indicated. The price per reactor as evidenced in Table 3 is the lowest for Process 200 Stage 1. In comparison to Process 300 Stage 1, the residence time makes it more expensive due to the number of trains. Although not reflected here, Process 200 Stage 1 also has an additional stage. Process 100 has only one reactor stage. Thus for both the Andritz and Anco-Eaglin quotes, the Process 100 with the longer residence time and the Alloy 825 metallurgy is the least expensive when considering installed reactor equipment only for the different processes. Process 200 Stage 2 will be more than $4 million, which is the difference between the installed cost for Process 100 and Process 200 Stage 1.

4.2 Scaling

The Andritz equipment cost will be used for scaling. If the production is to be scaled down by 20%, the installation cost can be adjusted by reducing the number of trains for Process 100 or 200 from five to four. A reasonably accurate price could be attained by multiplying the installed cost by 0.8. Likewise, an additional 20% increase in production would result in the 1.2 times price of either of these two process options. Taking the price to ±40% would be slightly less accurate due to the engineering costs associated with the equipment design, but this would still give a relatively good number based on this degree of accuracy. Likewise, Process 300 Stages 1 and 2 could be estimated relatively accurately at ±25% by adding or subtracting an additional train and multiplying the cost by ±25%.

5. CONCLUSION

There is a significant difference between the process options in terms of pricing. Process 100 has only one stage of reactors. Process 200 has two stages; therefore, the installed reactor cost for both Process 200 stages will be more than for Process 100. Process 300, which will include both Stage 1 and 2, is significantly greater in price with the zirconium-clad metallurgy.

Of the two vendors, Andritz is much more experienced in handling wood chips, and reactors identical to the ones quoted have been used in the pulp and paper industry since 1984. The Andritz equipment was based on a reactor level that was 40% to 50% full versus 95% full for Anco-Eaglin. Therefore, the Andritz reactors were larger in volume and in quantity. As a result, Andritz quoted more equipment and the resulting equipment cost estimate is higher. The resulting installation estimate, which is factored off the equipment, is higher as well. Andritz was more thoughtful in choosing the appropriate metallurgy for the mixers and feeders. This also added to the cost.

6. RECOMMENDATION

HGI recommends using the type of equipment proposed in the Andritz quote (i.e., plug screw feeders and process-appropriate metallurgy). The horizontal reactors should be tested for varying feed stock fill to determine if cooking is affected by percent full. The number of reactor trains and reactor sizing should then be based on experimental data for the chosen process. In addition, Process 300 Stage 2 density should be confirmed.