Enhanced Biomass Hydrolysis with Hot Wash Separation

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2003 AIChE Annual Meeting
Separation of Processing Streams Derived from Renewable Feedstocks (Session 162)

San Francisco, CA
November 20, 2003

Outline

- Background
- Reactors and filter
- Integrated pretreatment and "hot-washing" of yellow poplar sawdust and corn stover
- Digestibility of residual cellulose
- Conclusions

Background

- Lignin affects the enzymatic hydrolysis of pretreated biomass.
- Small amount of lignin is solubilized by dilute acid and steam pretreatments.
- Lignin may re-precipitate upon pretreated solids when cooled.
- Bench scale experiments show solubilized lignin can be removed by a flowing liquid medium at elevated temperatures.
- Enhanced enzymatic hydrolysis of residual cellulose to glucose.

Background

- Present pretreatment process is a dilute – acid prehydrolysis step followed by enzymatic hydrolysis of the residual cellulose to glucose.
- One possible improvement to this process is the inclusion of a "hot wash" step following the dilute-acid prehydrolysis.
- "Hot wash" concept developed at NREL (U.S. Pat. No. 6,228,177).

Background

Related Work

- Univ. Hawaii (Antal *et al.*)
  - Liquid hot water/steam in an immersion/percolation reactor
    - Batch steam and LHW immersion
    - LHW with intermittent addition and removal
  - Enhanced xylan solubilization, xylose recovery (oligomers), lignin solubilization, and enzymatic digestibility, especially at higher L:S ratios (>10:1)

Background

Related Work

- Dartmouth College—CAFI (Wyman *et al.*)
  - Liquid hot water and dilute to very dilute sulfuric acid
  - Batch, flowthrough, and start-stop flow regimes
  - Relates xylan removal, xylose recovery, monomer:oligomer ratio, lignin removal to flow regime
    - Function of flow rate, flow velocity, L:S, acid conc., *etc.*

Background

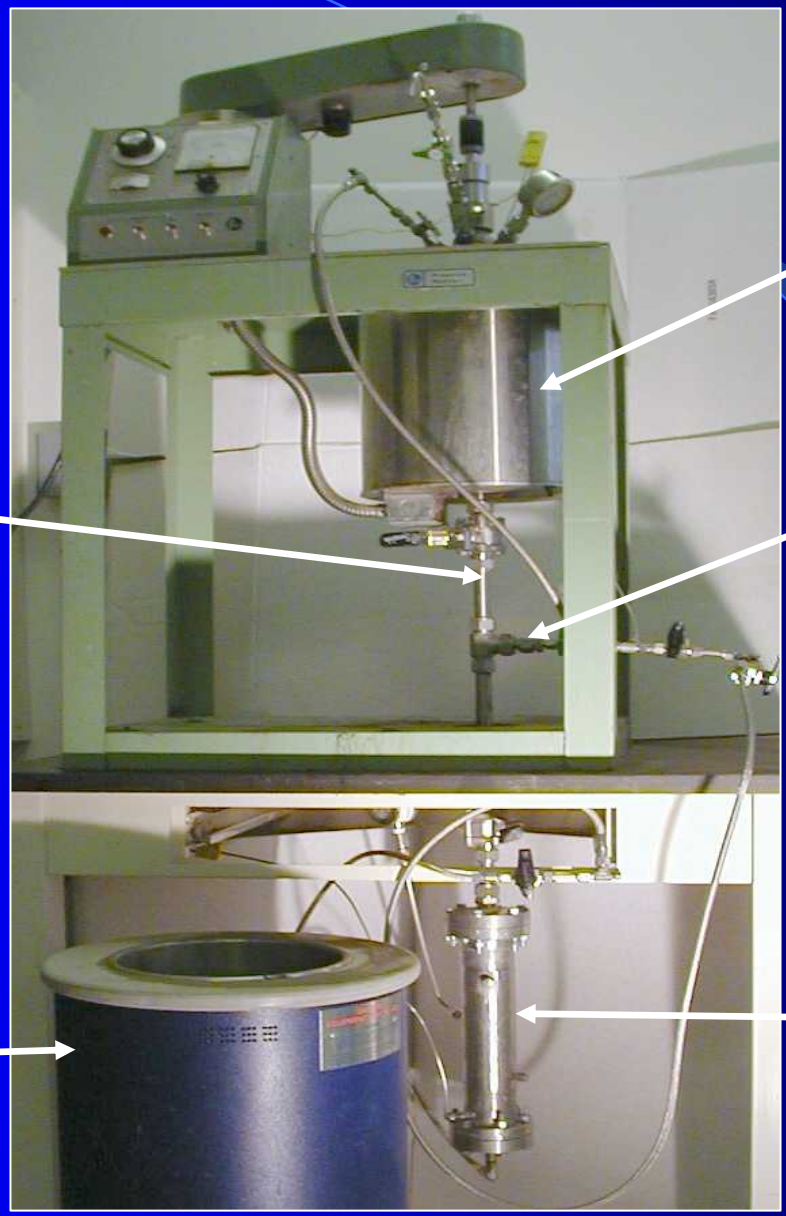
This work

- Outgrowth of flowthrough percolation "wonderwood" process
  - Greater xylan and lignin removal, higher xylose yields, resulting in enhanced enzymatic digestibility
- Technoeconomic analysis identified that high L:S ratio is a "show stopper"
  - Dilution effects
  - Steam demands to heat up required liquid volumes in pretreatment

This Work

- Decouple the pretreatment and separation/washing
  - High solids pretreatment (>25% solids)
  - "Hot" separation and washing
    - $Temp_{pretreat} > Temp_{s/w} > Temp_{lignin\ phase\ trans.}$
  - Validated in bench-scale device
  - Scaled to a pilot-scale system

Bench-Scale "Hot Wash" Test System



Stirred Parr Reactor (1 L)--inside heating mantle

Piping and Valve for Elevated Temperature Transfer from Parr Reactor to Pneumapress Filter Test Unit

Preheated Wash Liquor Addition

Heated Sand Bath

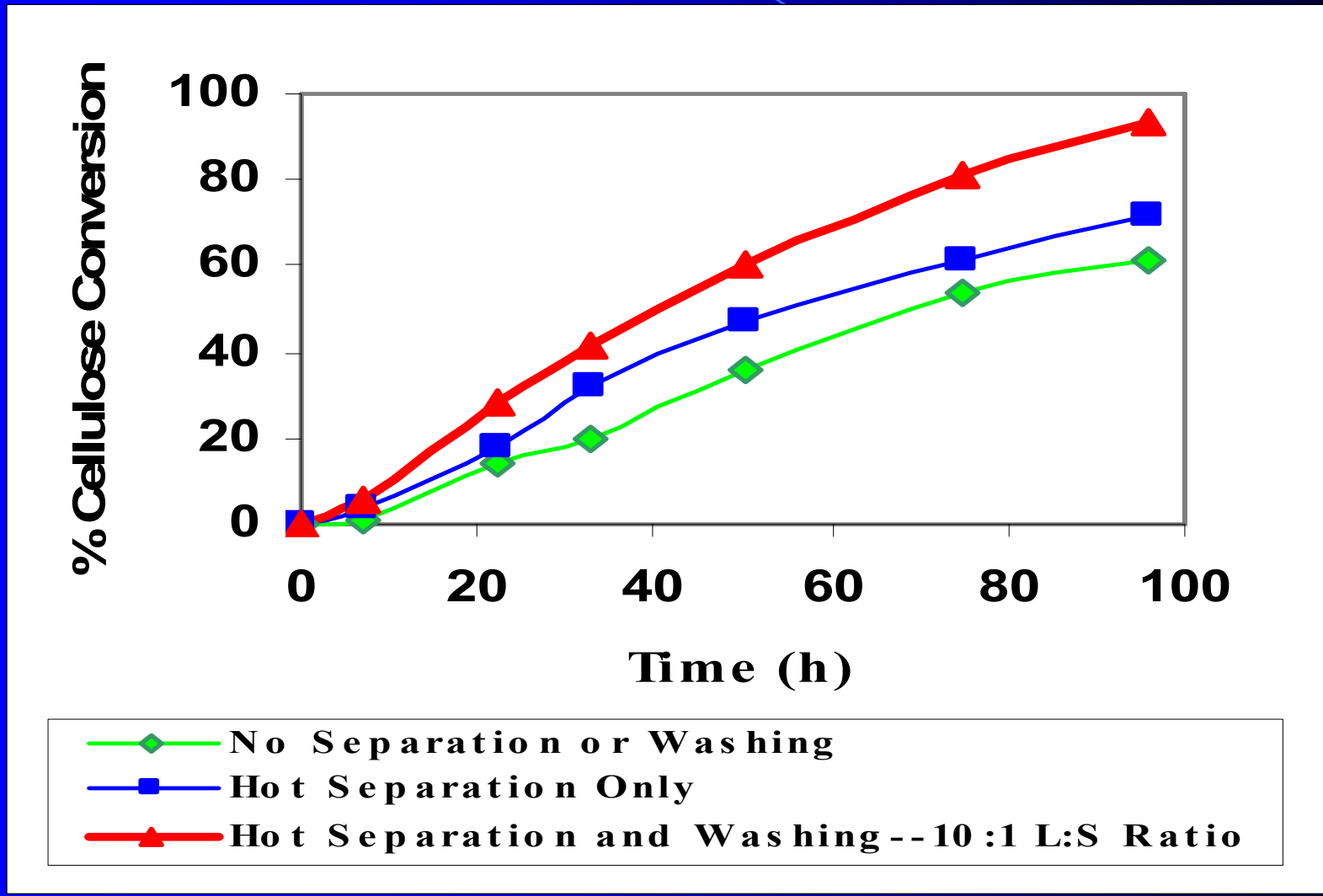
Pneumapress Filter Test Unit--inserted in heated sand bath during operation

Hot Wash Process Configuration

- Separation/washing can occur at lower temperature than pretreatment reaction
  - ~160-200°C for pretreatment reaction
  - ~130-140°C for separation/washing

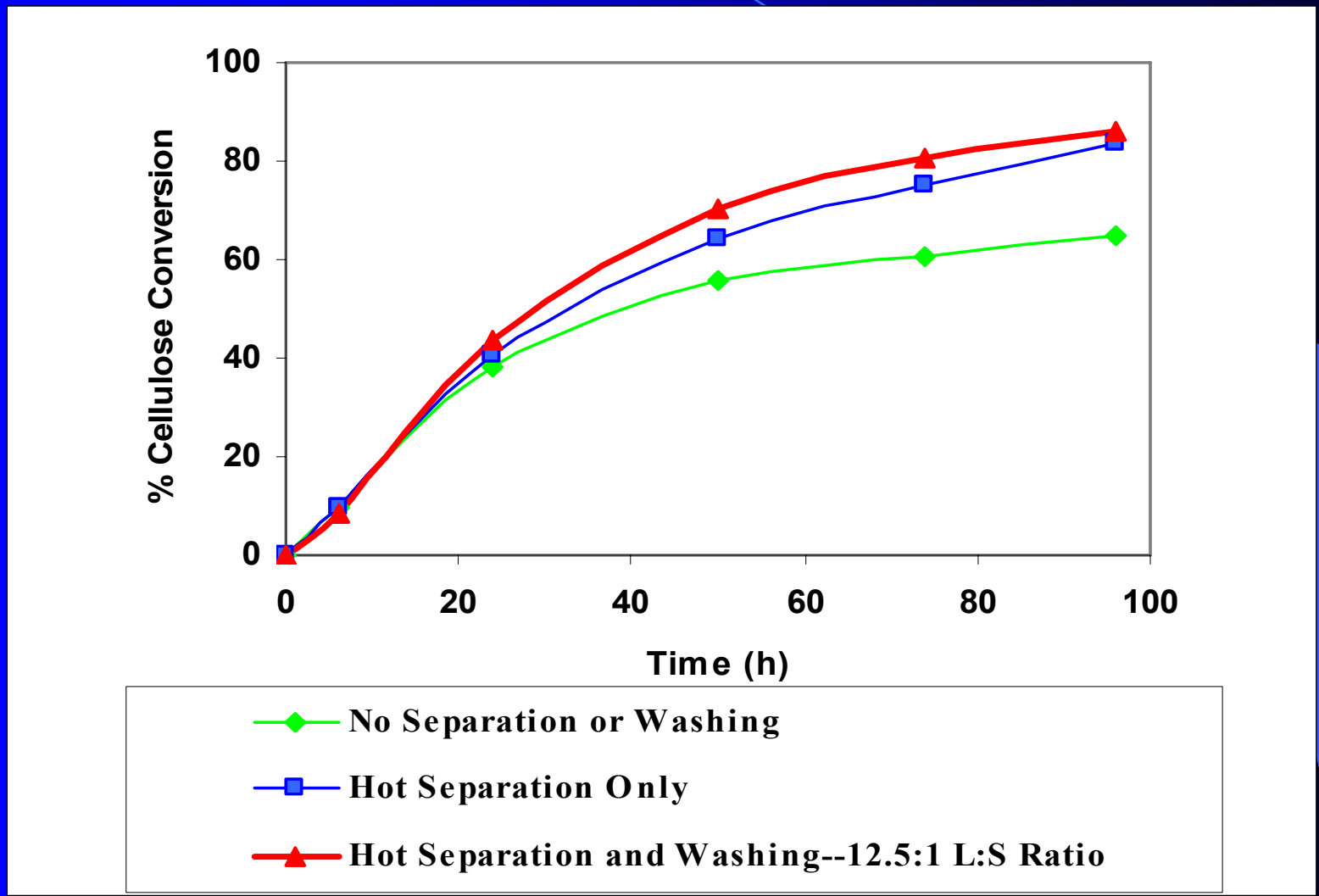
Enzymatic Digestibility of Hot Washed Pretreated Biomass from Bench Scale Equipment

Hardwood (Yellow Poplar)

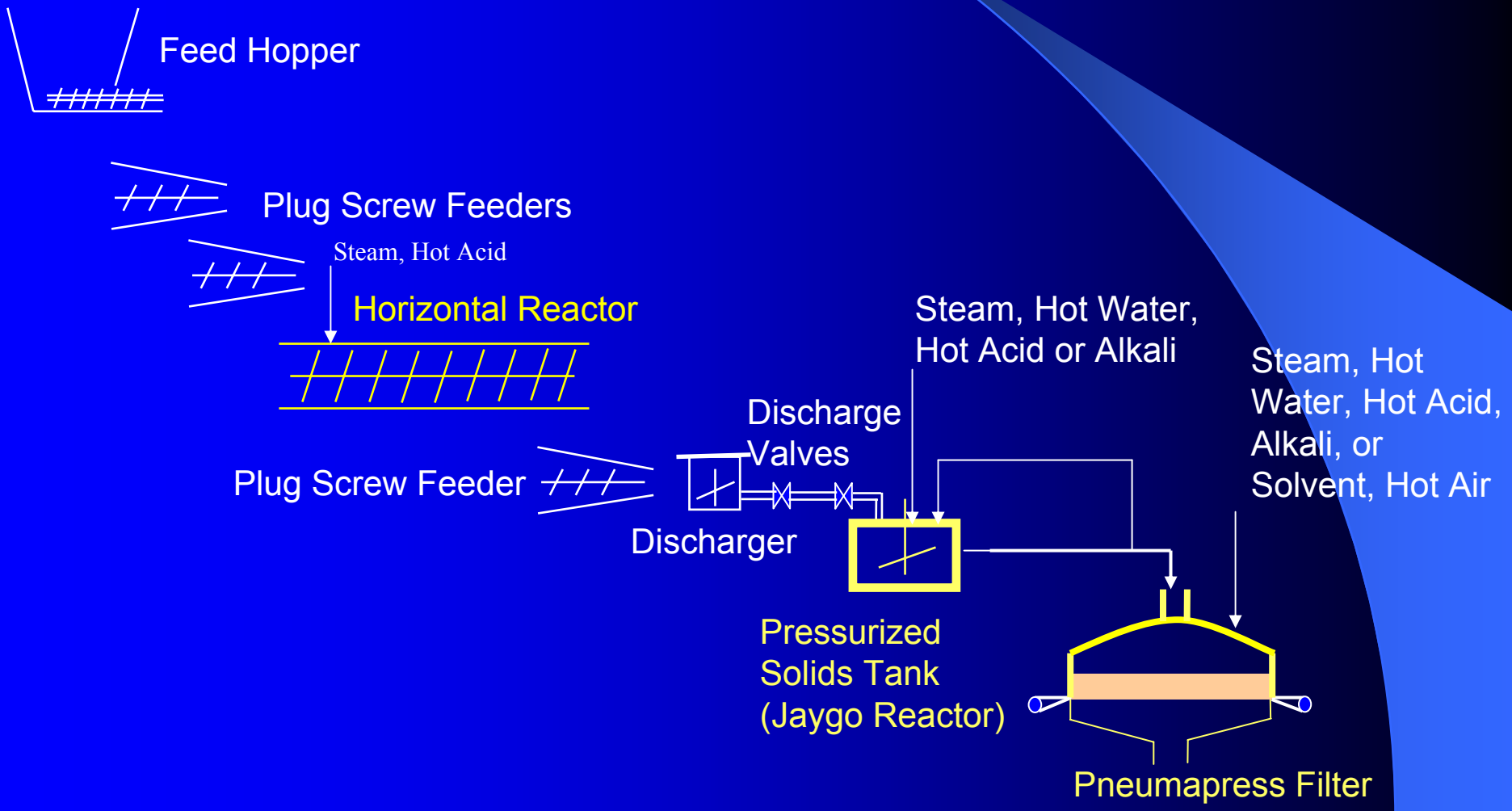


Enzymatic Digestibility of Hot Washed Pretreated Biomass from Bench Scale System

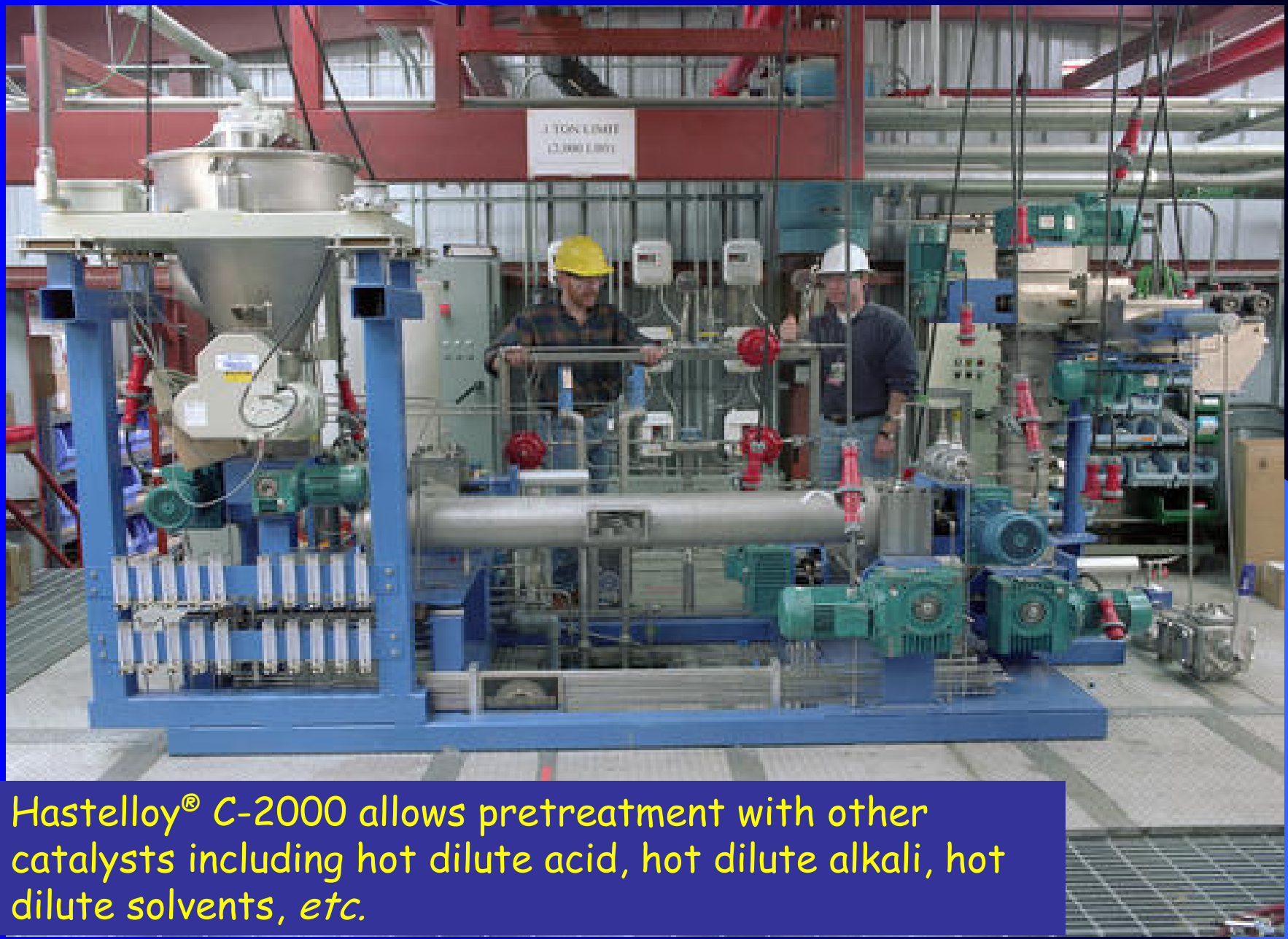
Corn Stover



Pilot Scale "Hot Wash" System

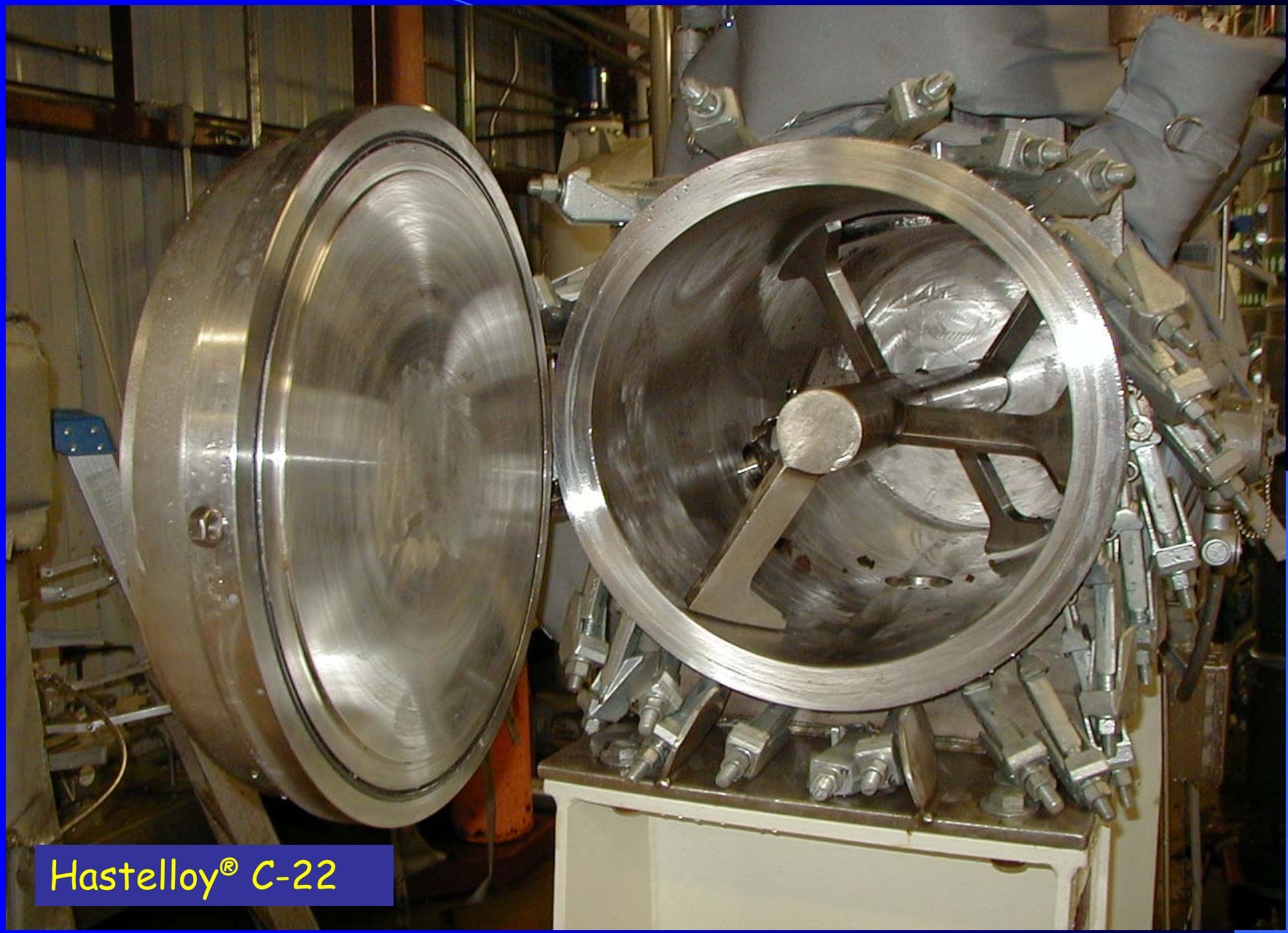


Sunds Horizontal Screw Reactor



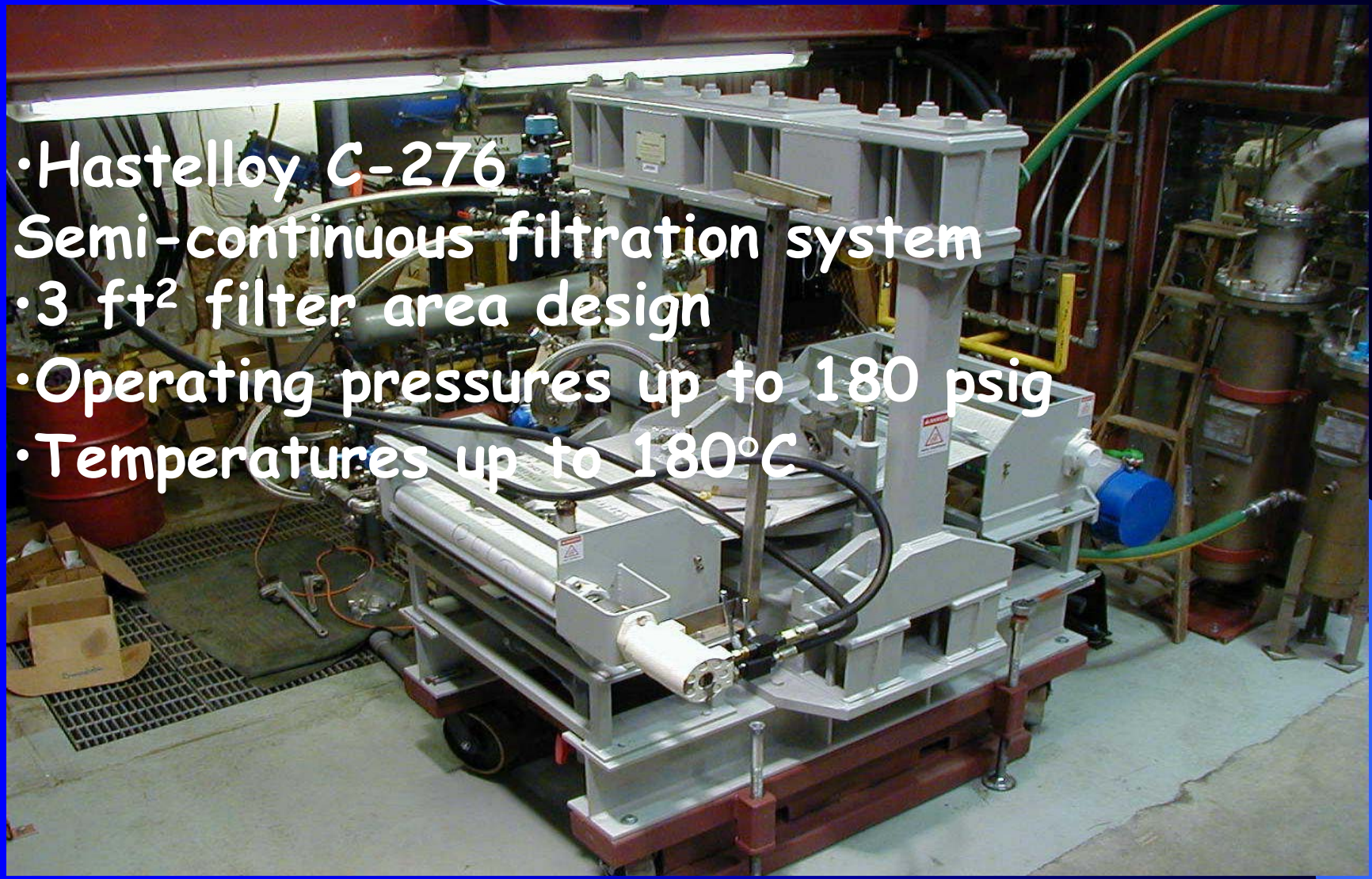
Hastelloy® C-2000 allows pretreatment with other catalysts including hot dilute acid, hot dilute alkali, hot dilute solvents, *etc.*

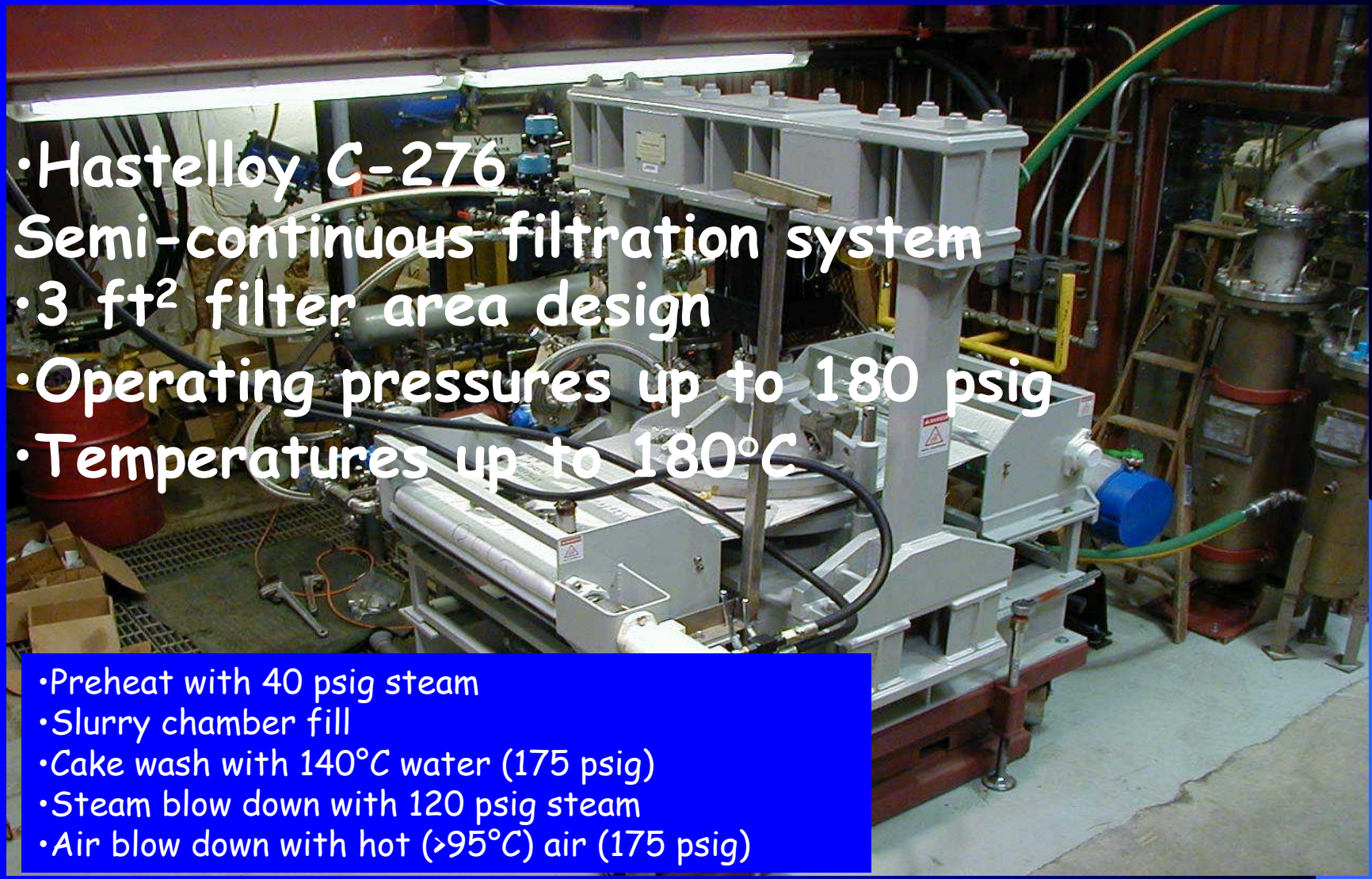
Jaygo paddle type batch reactor



Hastelloy® C-22

Pneumapress® Automatic Pressure Belt Filter


•Hastelloy C-276
Semi-continuous filtration system
•3 ft² filter area design
•Operating pressures up to 180 psig
•Temperatures up to 180°C

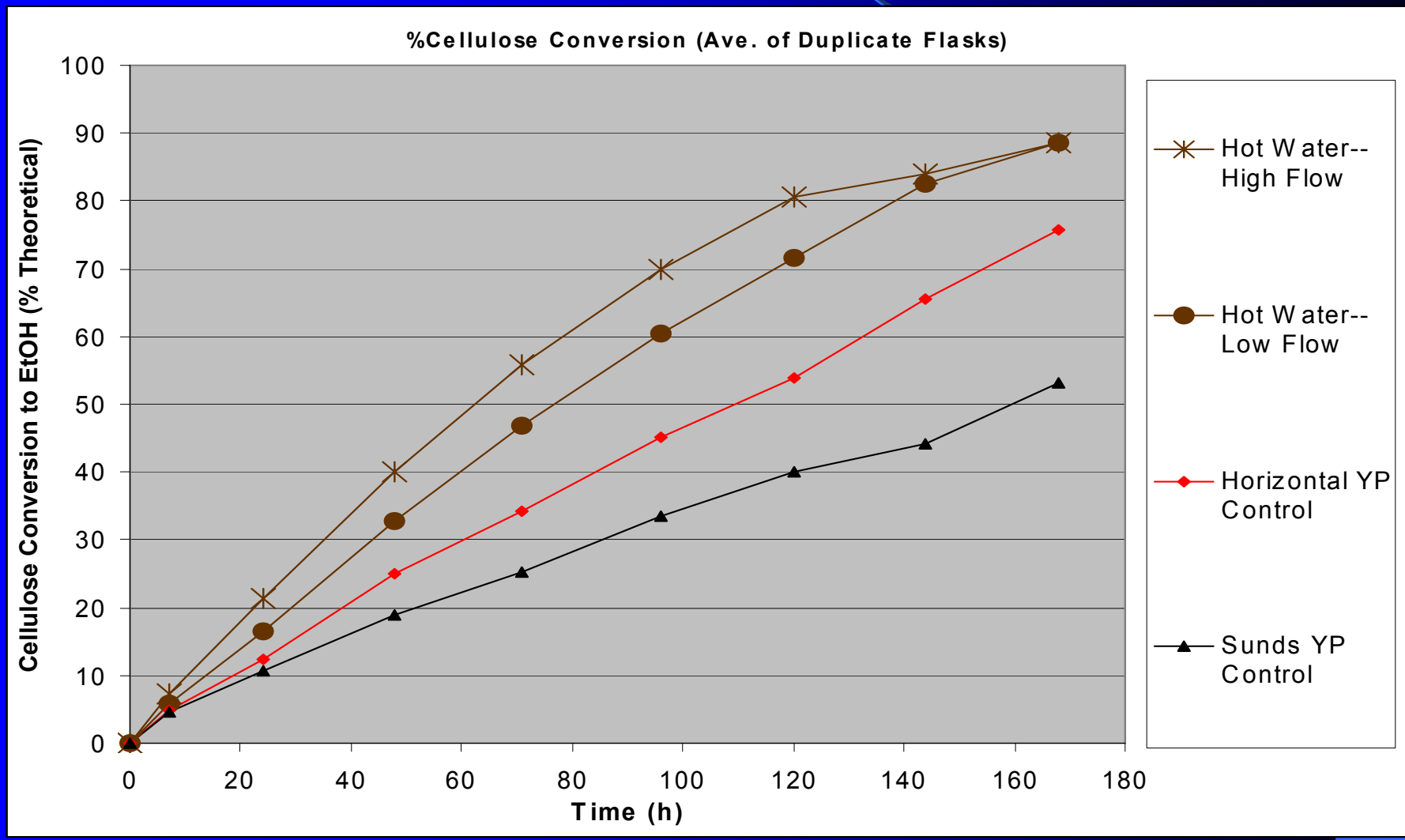


- Hastelloy C-276 Semi-continuous filtration system
- 3 ft^2 filter area design
- Operating pressures up to 180 psig
- Temperatures up to 180°C

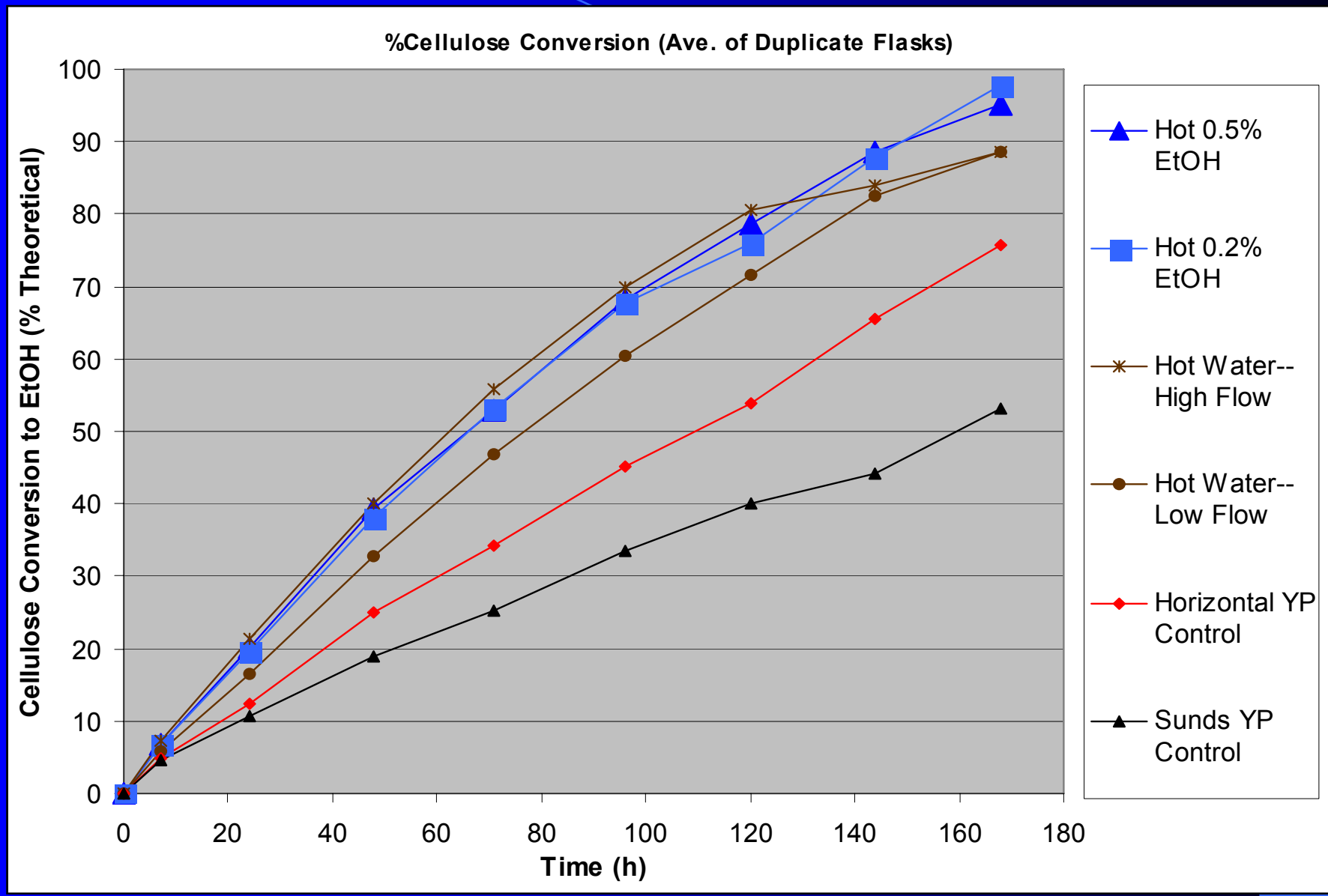
- Preheat with 40 psig steam
- Slurry chamber fill
- Cake wash with 140°C water (175 psig)
- Steam blow down with 120 psig steam
- Air blow down with hot (>95°C) air (175 psig)

Digestibility of "Hot Washed" Pretreated Yellow Poplar from Pilot Scale System

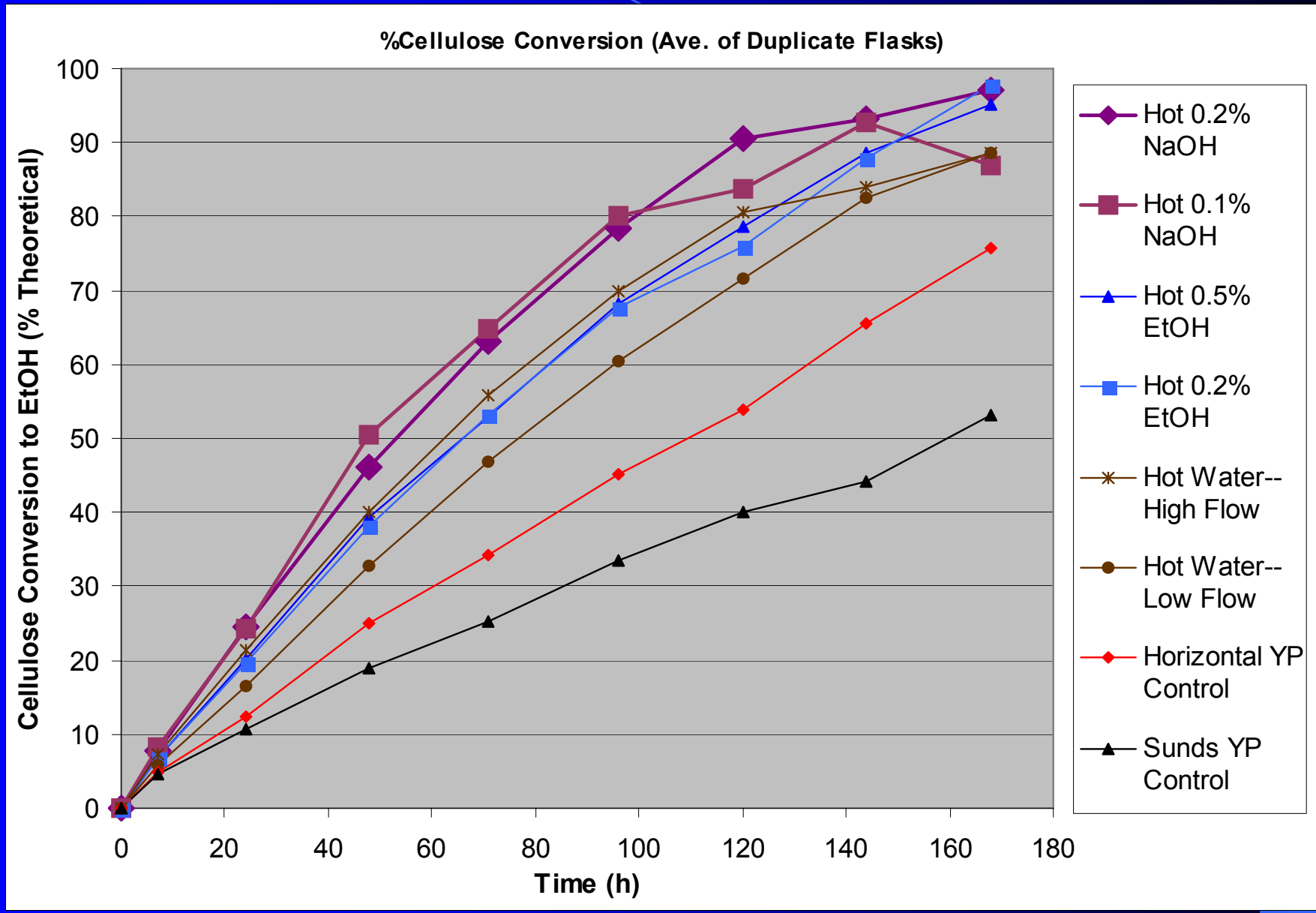
- SSF of Pretreated Yellow Poplar (175°C, 0.7% H_2SO_4, ~6 min)
- Cellulase loading: 20 mg protein/g cellulose (Genencor Spezyme CP) (~5 FPU/g cellulose)



SSF Digestibility of "Hot dilute Ethanol Washed" Pretreated Yellow Poplar from Pilot Scale

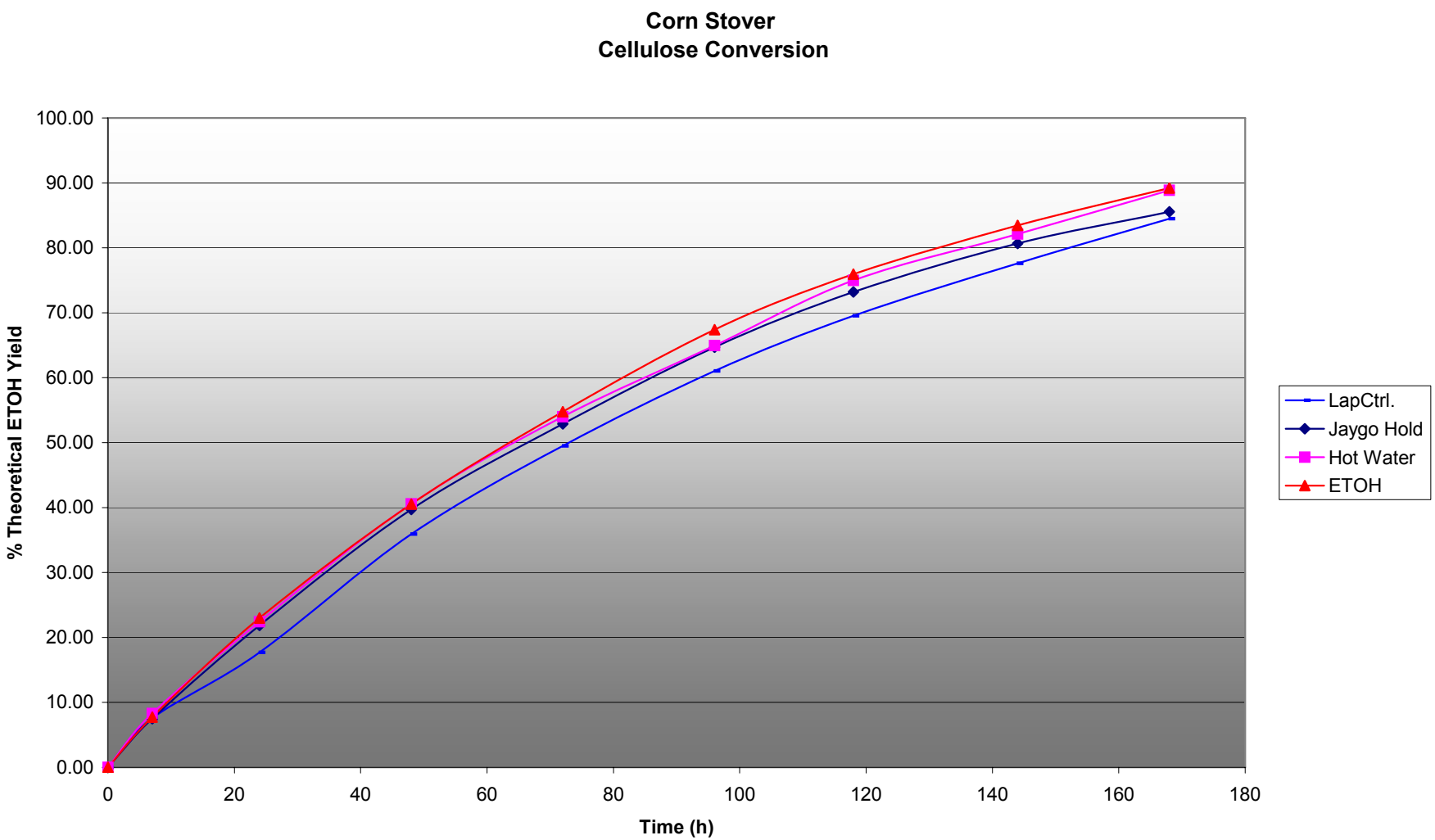


SSF Digestibility of "Hot dilute Alkali Washed" Pretreated Yellow Poplar from Pilot Scale



SSF Digestibility of Pilot-Scale "Hot Washed" Corn Stover from Pilot Scale System

- SSF of Corn Stover Pretreated in Jaygo Reactor(170°C, 0.5% H_2SO_4, 8 min)
- Hot washed at ~140°C
- Cellulase loading: 12 mg protein/g cellulose (Genencor Spezyme CP) (~3 FPU/g)



Sunds Vertical Hydrolyzer

Zirconium highly resistant to strong acids (*i.e.* HCl, H_2SO_4, HNO_3, acetic, formic, lactic, *etc.*) and strong bases

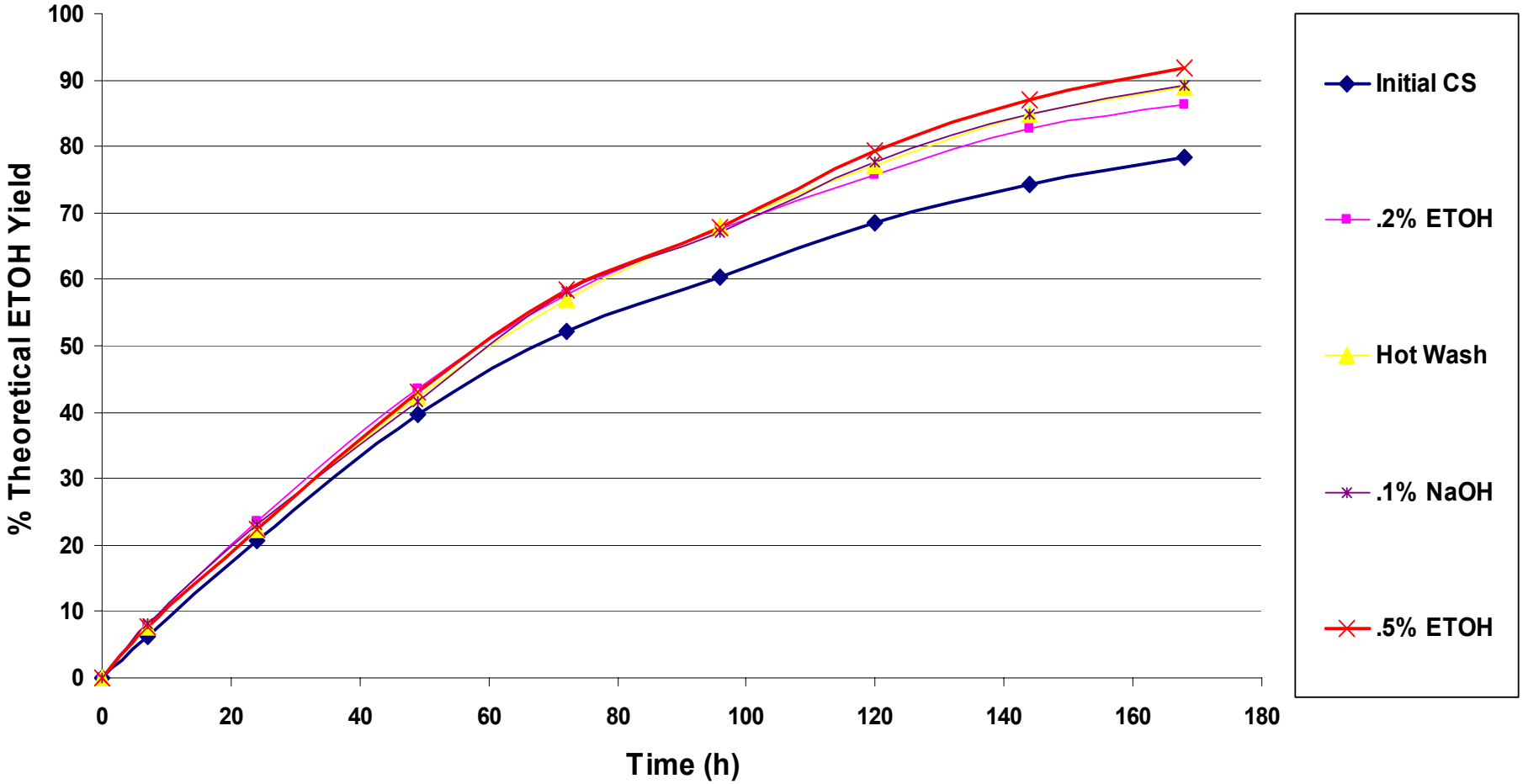
SSF Digestibility of Pilot-Scale "Hot Washed" Corn Stover

SSF of Sunds Vertical Reactor Pretreated Corn Stover (165°C-190°C, 1% H_2SO_4, ~5-8 min)

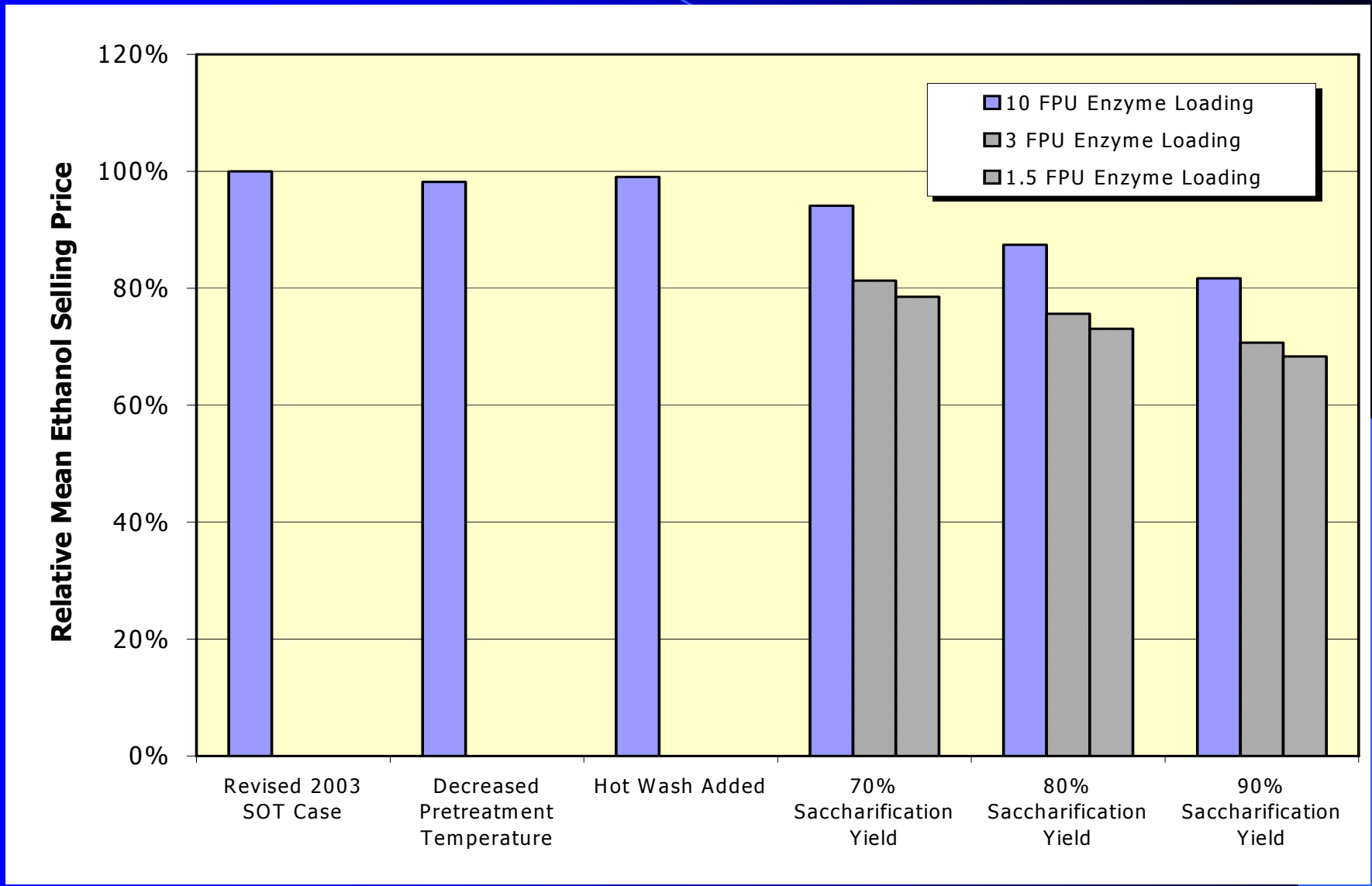
Pretreated solids allowed to cool before hot washing

Hot washed at ~140°C

Cellulase loading: 12 mg protein/g cellulose (Genencor Spezyme) (~3 FPU/g)



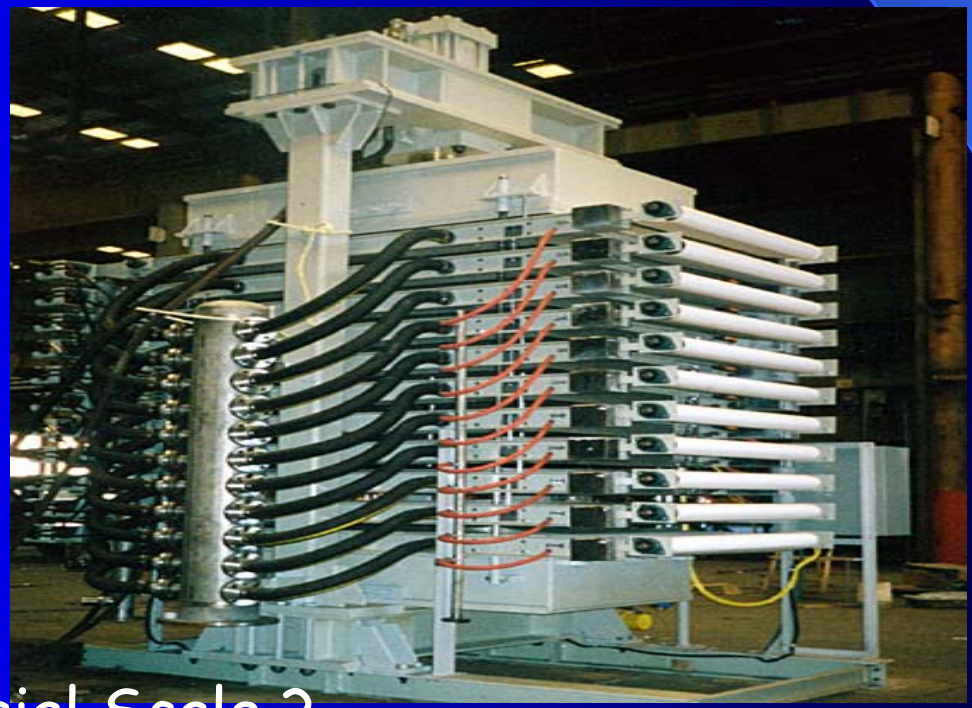
Economic Analysis of Hot Wash Process



Hot Wash Filters

Bench Scale

Pilot Scale



Commercial Scale ?

Conclusions

- Integrated pilot-scale "hot washing" system installed at NREL.
- "Hot washing" pretreated YP increased digestibility from 74% to 97%
- Low enzyme loadings (5-FPU/g of cellulose).
- "Hot washing" pretreated CS increased digestibility of cellulose from 78% to 90%.
- Low enzyme loadings (3-FPU/g of cellulose).
- Lower severity dilute-acid pretreatments of YP and CS gave high enzymatic digestibility of "hot washed" residues.

Conclusions

- "Hot washing" cooled pretreated corn stover significantly increased the digestibility of the residual cellulose.
- Selective washing processes can produce lignin-based co-products.
- Optimized conditions for Pneumapress solid/liquid separation could reduce time required for substrate bioconversion.
- Lower severity pretreatments may be achieved in less expensive pretreatment reactors
- High enzymatic digestion of the residual cellulose to glucose for fermentation to other bio-based products.

Acknowledgements

U.S. Department of Energy

Office of the Biomass Program

Steve Benesi, Patrick Costelloe, Tony Miller

Pneumapress Filter Corp., Richmond, CA