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 99-10600/18
ACID HYDROLYSIS REACTORS
BATCH SYSTEM

FEBRUARY 27, 2001

Harris Group Inc.
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Seattle, Washington 98109

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1. EXECUTIVE SUMMARY

The National Renewable Energy Laboratory (NREL) has requested that Harris Group Inc. (HGI) evaluate the design and capital cost of batch acid hydrolysis reactors for the biomass to ethanol process as a low-cost alternative to continuous reactors. Design and cost estimates to date for acid hydrolysis have been largely based on continuous reactors; however, continuous reactors typically have much higher capital costs than batch systems. This report describes the design basis and components of the reactor system, and provides an estimation of capital costs for a dilute acid hydrolysis system based on batch reactors.

This study was based on a single batch reactor that processes hardwood chips preimpregnated with sulfuric acid. Only equipment directly associated with the reactor is included, starting with the preimpregnated chips entering a batch feed bin and ending at the exit of the reactor blow valve. Steam supply, heat recovery systems, blow lines, blow tank, and associated processes are not included in the scope.

Short residence times of 2 to 3 minutes in the reactor at operating temperature and pressure are an essential requirement for effective two-stage dilute acid hydrolysis. This limits the maximum size of the reactor to the volume of feedstock that can be heated, by steam, to the desired temperature of 400ºF (205ºC) in 3 minutes. This results in a reactor with a maximum volume of 240 cu ft. The cycle time from fill to blow for a reactor of this volume would be approximately 9 minutes.

The major pulp and paper equipment vendors and the major pressure vessel fabricators declined to provide for the supply of the complete reactor system including capping and blow valves. HGI then developed a specification for a reactor vessel based on the "rapid cycle digester" design developed by the Bauer Company in the 1960s. Specifications for the capping and blow valves were developed separately based on HGI's experience in the pulp and paper industry.

The results of the quotations and estimated installation costs indicate that an Alloy-825-clad vessel with capping and blow valves of similar material are suitable for this application. The estimated equipment cost of such a system is $372,088 with an installation factor of 1.84, resulting in a total installed cost of $684,642.

It should be noted that the vendors were concerned about the frequent cycling of the vessel and warned that the life of the vessel would be considerably shorter than normal service. Further testing is required to define the stress placed on the vessel by this rapid cycling and to predict the expected service time of the vessel.

2. PAST PRACTICES FOR BATCH DIGESTERS

Dilute acid hydrolysis requires treatment with dilute sulfuric acid at high temperature for short reaction times. The metallurgy required for these conditions and the high pressures involved result in high equipment costs for the continuous system. The alternative of using batch reactors was considered. Although the potential size of a commercial ethanol system would require multiple batch units, the number is relatively small (10 to 14) due to the short cycle, enabling up to 120 batches a day to be made in one reactor. This rapid cycling does put high stresses on the equipment due to the large pressure and temperature swings during cycling. Continuous reactors, however, require high-cost components, screw feeders and mechanical feed systems and discharge valves, which have critical metallurgy and pressure requirements.

Batch digesters are used in standard practice by the pulp and paper industry. Maximum pressures are generally below those required for biomass hydrolysis. The acid sulfite pulping process uses relatively high pressures (150 psig), has severe acid conditions, and is generally conducted in batch digesters. Some specialty processes such as the Alcell solvent pulping system require higher pressure (160 psig).

Cycle time for a typical wood pulp cook is in the range of 200 to 350 minutes. Typical sulfite mills have 5 to 10 digesters to produce 400 to 600 tpd of pulp using 700 to 1100 odmtpd of wood chips. Batch kraft mills exist with up to 20 digesters and process up to 2200 odmtpd of chips.

Short residence times of 2 to 3 minutes are an essential requirement for an effective two-stage dilute acid hydrolysis. Carbohydrate degradation products such as furfural and HMF are formed when this short reaction time is extended. This lowers the carbohydrate yield and these degradation products are potentially toxic to downstream fermentation organisms.

The large size of typical pulp mill digesters is not compatible with the required cycle for biomass hydrolysis. Two examples of short cycle batch digestion systems for wood chips come from the fiberboard area: the Masonite explosion gun and the Bauer rapid cycle digester.

2.1 Masonite Explosion Process

Information on the Masonite gun was obtained from the original patents (Refs 1, 2, and 3), contact with Masonite Corporation personnel, and an USDA publication (Ref 4). Details of the digester and the cycle used are shown in Table 1.

Multiple reactors with small chambers were used, allowing rapid filling, steaming and explosive release of the heated material. The Masonite gun processed 80 od lb of wood each charge and reached a steam pressure up to 1000 psig in a 30- to 40-second treatment before blowing.

About 35 Masonite guns were constructed. Twenty five were located at the Laurel, Mississippi Masonite plant, now part of International Paper. Five were in a plant in California and five in Canada. The company moved to use of Defibrator continuous digesters and refiners starting in the early 1970s. The last gun was retired in the early 1980s. Energy conservation was the main reason for abandoning the process but yields were also low.

Table 1
Comparison of Cycle Times and Proposed Design Conditions

	Masonite Gun	Bauer Rapid Cycle Digester	Standard Kraft	Standard Sulfite
Typical digester size, cu ft	10	120 to 250	5200	5000
Wood charge, odmt	0.035	0.5 to 0.7	25	22
Typical cycle				
Chip fill	15 sec	1 min	15 min	15 min
Close cap	2 sec	0.5 min	5 min	5 min
Steaming	10 sec	2 min	115 min	120 min
Hold	40 sec	2 min	45 min	120 min
High pressure	8 sec	–	–	–
Pressure relief	–	1 min	20	60 min
Blow	3 sec	1 min	15 min	15 min
Open cap	2 sec	0.5 min	5 min	5 min
Total cycle time	80 sec	8 min	220 min	340 min
Maximum pressure, psig	1000	300	145	150
Blow pressure, psig	1000	50	50	30
Reactors required for 2000 odmtpd	50	14	12	21

The cycle use in the Masonite gun was about 1.5 minutes. Calculations based on published production rates and the digester size indicate actual plant operation had an average cycle time of 2.4 minutes. Approximately 70 guns would be needed to treat 2000 tpd of hardwood chips in a biomass plant.

2.2 Bauer Rapid Cycle Digester

The Bauer Company developed a larger digester to treat wood before refiner defiberization. It was termed the "rapid cycle digester" (Refs 4 and 5). It had a larger capacity, 1200 to 1500 od lb, and operated at lower pressure (250 psig) than the Masonite gun.

A description of this short cycle digester was provided in an USDA publication (Ref 4). A paper by a Bauer employee, C.K. Textor, provides further details of the digester design and cycle (Ref 5).

The digestion cycle is shown in Table 1. After the chip fill and deaeration with steam, the pressure was raised to a maximum of 300 psig and held for a short period, then relieved to about 50 psig before the blow valve was opened. The chips were not defiberized by the digestion treatment or blow and were defibered in a subsequent disc refining stage.

The cycle time used in the Bauer system was 6 minutes. The digest capacity was 100 to 200 cu ft. Based on a charge of 0.6 odmt of wood, only 14 reactors would be required to process 2000 odmtpd of wood.

Specific design considerations to enable rapid filling, uniform steaming and clean discharge were noted by Textor:

- The diameter-to-height ratio of the cylindrical portion is approximately 1:4.
- The open area of the chip feed valve is 30% of the vessel cross-sectional area.
- The blow valve open area is 8% to 12% of the vessel cross section.

Andritz Inc. (the current owners of the Bauer technology) located a person with previous digester experience. (See Appendix B, Andritz-Bauer.) Only a few were built in the early 1960s and as far as is known none are now in existence. The extra information about the design of the digester was that the lower cone must have a shallow taper and the taper to the blow valve must be smooth to allow clean blowing of the chip mass. The working volume should be about 80% of the total volume, again to aid in clean discharge at the blow and to prevent blowing of chips in the pressure relief stage.

As Andritz stated that they had no current interest in supplying this type of reactor, steps were taken to develop the reactor design for fabrication by pressure vessel fabricators.

3. DESIGN OF BATCH HYDROLYSIS REACTOR

3.1 Reactor Design

The conditions required for the single-stage hydrolysis were taken from those set for the continuous reactor design (Ref 6). Discussion with Andy Aden of NREL confirmed the need to limit the time to maximum pressure at 2 to 3 minutes and time at maximum temperature at 2 minutes. The operating pressure and temperature is 17 atmos (250 psig) and 400ºF

(205ºC). The vessel would be designed to allow operation to a maximum of 300 psig and 435ºF (225ºC). The proposed cycle sequence is outlined in Table 2.

Table 2
Batch Hydrolysis Reactor Cycle

	Proposed Design
Reactor size, cu ft	240
Wood charge, odmt	0.8
Typical cycle:	
Chip fill, minutes	1
Close cap, minutes	0.5
Steaming, minutes	3
Hold, minutes	2
Pressure relief, minutes	1
Blow, minutes	1
Open cap, minutes	0.5
Total cycle time, minutes	9

In addition to the batch dilute acid reactor described in the previous paragraph, an estimate was also prepared for a lower pressure reactor. This reactor would operate at a lower temperature (180ºC) and pressure (150 psig) with no sulfuric acid. In this case, 316L stainless steel is suitable metallurgy.

The Bauer rapid cycle digester was chosen as the model for the biomass hydrolysis batch as this type of digester has previously proven to operate under conditions very close to those required in the dilute acid hydrolysis process and could provide an economical system in comparison to the continuous alternative. No alternative designs were identified that would provide added benefits over the Bauer digester.

Metallurgy suitable for the hydrolysis conditions has been identified for the continuous reactors and is most likely suitable for batch reactors (Ref 7). However, the stationary batch reactors can be constructed of steel and lined with acid-resistant brick. Such an approach is used in most acid sulfite digesters. Carbon brick lining is considered suitable for the sulfuric acid concentrations in the hydrolysis stage by the lining service companies, RECOR and Stebbens.

A design was established for the biomass batch reactor based on the Bauer rapid cycle digester. Specific design specifications are listed in Table 3. The proposed cycle sequence is shown in Table 2.

Table 3
Batch Hydrolysis Reactor Design

	Reactor
Reactor capacity, cu ft	240
Wood charge, odmt	0.8
Dimensions:	
Main cylinder diameter, ft	4
Main cylinder height, ft	16
Bottom cone height, ft	6
Capping valve ID, in.	18
Blow valve ID, in.	10
Operating temperature, °C	205
Operating temperature, °F	400
Operating pressure, psig	250

A reactor with 240 cu ft total volume was selected. This is slightly larger that the range stated in the literature for the Bauer digester. The larger size maximizes the chip capacity while still allowing rapid and uniform steaming to meet temperature cycle requirements. The reactor would have a diameter of 4 ft and a height of 16 ft in the cylindrical section. This would allow a wood charge of approximately 0.8 odmt based on 9 to 10 od lb/cu ft chip density. Use of a larger reactor size would compromise the required short steaming time and result in nonuniform treatment of the chips.

The capping valve specified is a ball type valve with an 18-in. ID opening. This type of valve is now standard for batch digesters in the pulp and paper industry and gives more reliable performance than the gate or cap-and-yoke type valves used earlier. Both these types of valves were subject to rapid deterioration of the seals and hang-up of fine wood material in the seal area. High reliability will be necessary with the high-frequency cycling in the batch hydrolysis situation.

The open area of the 18-in. valve is 14% of the reactor cross-sectional area. This is less than that described for the Bauer digester (30%), but considered to be satisfactory due to the clean internal channel and pulp mill experience, which has shown satisfactory performance with chip flows up to 250 cfm.

A ball valve is also specified for the blow valve. Most of the pulp and paper batch digester blow valves are ball type. A 10-in. valve gives an opening of 4.3% compared to the vessel cross section. This is lower than the Bauer design of 8% to 12% but, again, the smooth internal channel will aid the discharge and provide a clean blow. This size of valve is used for pulp digesters at much higher flow rates.

3.2 Reactor Process Description

The chip impregnation and conveying system are not included as part of the scope of this study. The conveyor would typically be an enclosed screw type with bottom discharge gates along its length as required for the number of reactors in the system. The gates are automatically controlled to discharge chips into the individual batch sizing bins above each reactor. The conveyor would be arranged with continuous feed and excess chips would discharge at the end and be recycled back to the feed end. Each bin has an internal level sensor or strain gauges incorporated into its support beams. The conveyor gate is opened until a preset level or weight is reached, representing a single reactor fill.

The reactor cycle begins with the closing of the blow valve, after completion of a blow. The capping valve is opened, then a slide gate on the bottom of the chip bin opens and the batch of chips drops into the reactor. The capping valve is closed and the relief valve is opened. Low-pressure steam (50 psig) is introduced into the reactor by the steaming nozzles and flows for a period of 30 seconds suitable to displace the majority of the air entrained with the chips during the fill. At that point the relief valve is closed and high-pressure steam is introduced into the reactor through the steaming nozzles. The estimated steam usages are 0.86 kg/kg od wood for the low-pressure and 0.84 kg/kg od wood for the high-pressure steam. The number of nozzles (four) is based on the Bauer design.

On reaching the set maximum pressure, the pressure set point is maintained for the required retention time by a pressure control loop. At the end of the retention time the steam supply is shut off and the pressure relief valve is opened a preprogrammed degree, allowing the pressure to drop until a set blow pressure is reached. Steam from the relief line normally passes through heat exchangers for energy conservation and to avoid explosive blow at discharge, which might damage equipment. Heat recovery could provide hot water or low-pressure steam for use in heating chemical solutions for impregnation or in later stages of the process such as distillation.

Upon reaching the set blow pressure, the relief valve is closed and the blow valve is opened, rapidly discharging the chips and steam through a blow line to a blow tank. The blow line and blow tank are not included in the scope of this design and estimate.

The system will be controlled by a central distributed control system (DCS) to give a fully automated process sequence of chip batch sizing, reactor filling, steaming, relief, and blowing. All valves will be automated and sensors will be provided to sense all required process conditions. Two operators could operate a system of five or six reactors. An additional operator would be required for up to 12 reactors. These operators would be responsible for the system including the chip feed conveyors to the blow tank.

The equipment associated with the batch hydrolysis system is described below.

3.2.1 <u>Chip Metering System/Chip Bin</u>

The 316 stainless steel chip bin is 5 ft in diameter by 15 ft high and operates atmospherically with typical chip temperature of 60ºC (140ºF). It has an open top and a conical bottom with a wide gate valve at the bottom.

3.2.2 Batch Size Sensor

Either a level sensor inside the chip bin or strain gauges on the bin supports could be used. The accuracy level required is not high as there is no need for proportioning chemicals and the design criteria for the reactor allows 20% free space.

3.2.3 Automatic Capping Valve

A ball type capping valve of 18-in. ID has been specified. All metal parts in contact with the chips will be special alloy or stainless steel as noted in the design criteria.

3.2.4 Reactor

The dimensions off the reactor are as shown in Table 3 and in Figure 1. The reactor is to be fabricated to industry standards and with the capability of operating through the needed short pressurization and temperature cycles. The specification used to request reactor fabrication prices is included in Appendix B.

Industrial Alloy Fabricators, who provided a price quotation, noted that with the frequent pressure and temperature cycling the vessel life is estimated to be approximately 10 years rather than the normal standard of 20 years.

The reactor will be supplied with

- Steam distribution consisting of four nozzles located near the bottom of the cylindrical section of the reactor (Note that the steam supply is not included in the scope of this estimate.)
- A relief valve to allow degassing of entrained air at the beginning of the pressurization cycle and relief of pressure from the maximum pressure down to the blow pressure
- Fittings for temperature and pressure sensors
- Exterior flanges for attachment to supporting elements

3.2.5 Blow Valve

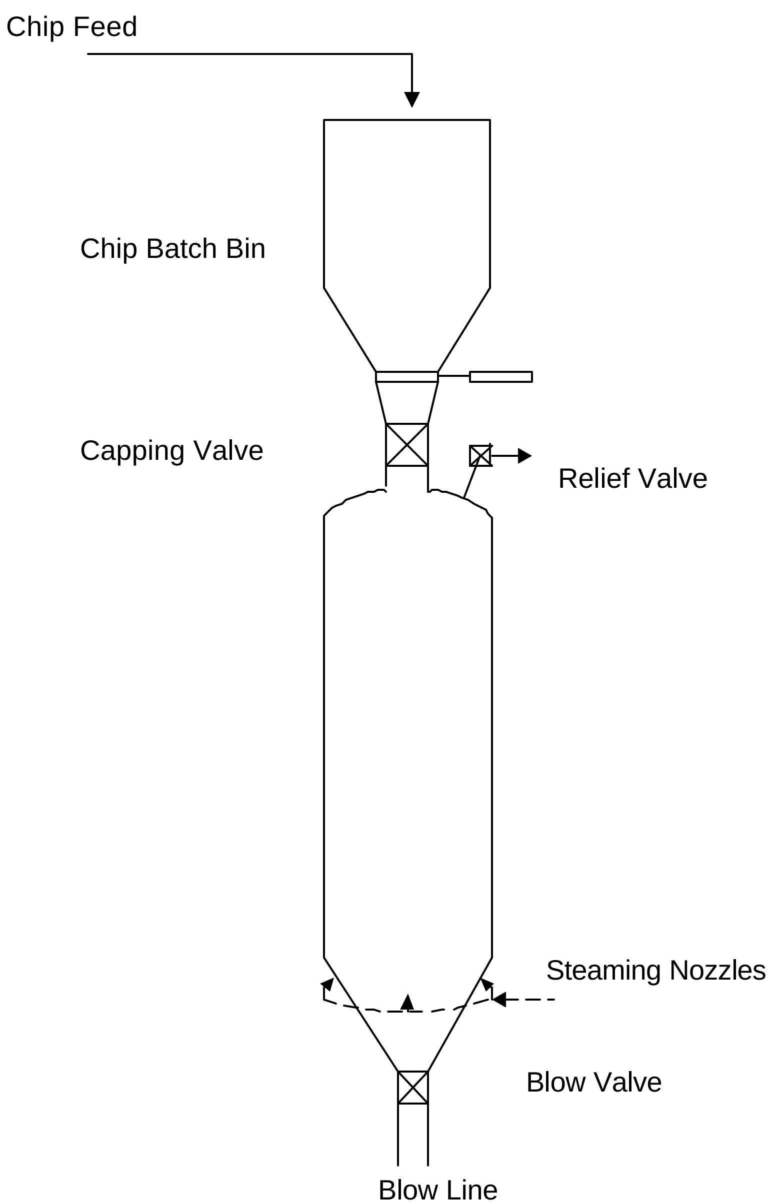
The blow valve will be a 10-in. ID ball type valve which, when open, will have a smooth channel to aid in clean discharge of the chip mass. The valve will be clad with the required alloy on all surfaces coming into contact with the chip mass. Other parts will be stainless steel

3.2.6 Instrumentation

A DCS is provided for sequencing the reactor cycle with sensing of the chip batch size, temperatures, and pressures. Safety interlocks are provided.

Figure 1

Proposed Short Cycle Digester



Chip Bin--5' diam x 15'

Capping Valve 18" ID

Digester--
Main section--4' diam. x 16'

Blow valve--10" ID

3.2.7 Metallurgy

Metallurgy specifications were based on corrosion testing and literature information presented in the Harris report – Project 99-10600 (Ref 7). Three alternative systems are evaluated. Two are designed for conditions required in the single stage. These conditions require a high resistant alloy either Hastalloy C2000 or Nickel Alloy 825. As an alternative for these conditions a reactor lined with carbon brick is estimated. A third alternative is a stainless steel construction designed for the first stage conditions for a two stage hydrolysis.

Three alternative cases were estimated as described below.

Alternative 1

Dimensions and pressures as shown in Table 3.

Materials of Construction: Capping valve, reactor and blow valve, nickel alloy 825 or Hastalloy C2000 cladding on all process exposed surfaces.

Alternative 2

Dimensions and pressures as shown in Table 3.

Materials of Construction
- Reactor body carbon steel with 6 ft diameter
- Acid brick/carbon brick lining
- Capping valve and blow valve nickel alloy 825 or Hastalloy C2000 cladding on all process exposed surfaces

Alternative 3

Dimensions as shown in Table 3. Maximum pressure 150 psig.
Materials of Construction: Capping valve, reactor and blow valve, 316 stainless steel.

4. EQUIPMENT AND INSTALLATION COSTS

None of the major pulp and paper equipment manufactures or the major pressure vessel fabricators were willing to provide quotes for supply of the complete reactor system including capping valve and blow valve. Two major pressure vessel designers and fabricators, Nooter Fabricators Inc. and CBI-Walker, stated that smaller pressure vessel fabricators could easily underbid them on vessels of this size. (See Appendix B, Nooter and CBI-Walker.) Major pulp and paper equipment suppliers, Valmet/Sunds, Andritz, and GL&D (Beloit), also stated no interest in supplying this type of specialized vessel. (See Appendix B, Andritz, Valmet, and GL&D.) Therefore, smaller pressure vessel fabricators were contacted and pricing was obtained for the vessel and valves separately.

Two companies who supply reactor brick lining services to the pulp and paper industry, RECOR Services and Stebbins Engineering, were contacted. RECOR conducted a review of the design needs and declined to provide pricing due to its assessment that a brick-lined vessel would not have a satisfactory service life due to the frequent rapid cycling of pressure and temperature. (See Appendix B, RECOR.) RECOR also declined to price the alloy vessel, as it would have to go to a third party to have the fabrication performed.

Stebbins declined to provide pricing for the fabrication of the vessel but did provide a budget cost for brick lining a reactor of the specified size. Stebbins did not thoroughly assess the expected service life. (See Appendix B, Stebbins.)

Velan Valve Corporation, Montreal, has a series of ball valves used for reactor capping called CAP-TIGHT. These ball valves range from 12- to 30-in. ID full port size and are rated to pressures of 150 to 300 psig. They provided a quote for a stainless steel valve but were unable to quote on a valve with Alloy 825 or Hastalloy C2000. Valmet provided a quote for Jamesbury 18-in. capping valves.

Two companies supplying ball valves suitable for blow valve service, Liberty Equipment, Seattle, Washington, and DeZurik Valve, represented by Tourangeau Nor West, Tualatin, Oregon, were identified. Liberty offered a price for a stainless steel valve only. A price quotation was obtained from DeZurik.

Two pressure vessel fabricators previously found to be reliable in other Harris Group projects agreed to provide budget pricing for the three reactor alternatives. Industrial Alloy Fabricators, Forest Grove, Oregon, provided estimates for all three alternatives. Wayron, Longview, Washington, only provided a price for the low-pressure stainless steel reactor.

Price quotations received from the vendors are summarized below.

4.1 Capping Valve

- 18-in. capping valve, Alloy 825 or Hastalloy C2000 (Jamesbury) $105,000
- 18-in. capping valve, 316L stainless steel (Jamesbury) $ 52,000
- 18-in. capping valve, 316L stainless steel (Velan) $ 51,300

4.2 Blow Valve

DeZurik by Tourangeau Nor Wes Corp, Tualatin, Oregon

- 10-in. blow valve, Hastalloy C2000 (300 psig) $104,088
- 10-in. blow valve, 316L stainless steel (300 psig) $ 34,065

Liberty Automation, Seattle, Washington

10-in. blow valve, 316L (150 psig) $ 19,027

4.3 Reactor Vessel

Industrial Alloy Fabricators

- 48-in. ID diameter, batch reactor, Alloy-825-clad $ 53,000
- 48-in. ID diameter, batch reactor, 316L stainless steel $ 33,000
- 72-in. ID diameter, batch reactor, carbon steel $ 29,500

Wayron Fabricators

48-in. ID diameter, batch reactor, 316L $ 45,000

4.4 Brick Lining

Stebbins Engineering

Two-course acid brick and carbon brick with liner of 72-in. ID reactor $110,000

4.5 Chip Bin

HGI estimated cost $ 15,000

5. CONCLUSION AND RECOMMENDATIONS

The installed costs for the three alternative systems are summarized in Table 4, below. The installation factors are based on HGI's experience on previous installations of a similar nature. It should be noted that these costs are based on a single batch reactor. Feedstock conveyors, steam supply, heat recovery systems, blow lines, blow tank, and associated processes are not included in the scope.

Table4
Equipment and Installed Cost

Alternative	Equipment Price*	Installation Factor	Total Installed Cost
1 (Alloy 825)	$277,088	2.13	$590,000
2 (brick lining)	363,588	1.86	677,000
3 (316 stainless steel)	118,327	3.64	431,000

* Equipment price includes chip bin, capping valve, reactor vessel, and blow valve.

The results of the quotations and estimated installation costs indicate that an Alloy 825 clad vessel with capping and blow valves of similar material are suitable for this application. The vendors were concerned about the frequent pressure and temperature cycling of the vessel (160 cycles per day) and warned that the life of the vessel would be considerably shorter than normal service. Further testing is required to define the stress placed on the vessel by this rapid cycling and to predict the expected service time of the vessel.

6. REFERENCES

1. US Patent No. 1,578,609, "Process and Apparatus for Disintegrating Wood and the Like," Mar 30, 1926.

2. US Patent No. 1,655,618, "Apparatus for and Process of Explosion Fibration of Lignocellulose Material," Jan 10, 1928.

3. US Patent No. 1,824,221, "Process and Apparatus for Disintegration of Fibrous Material," Sept 22, 1931.

4. "Fiberboard Manufacturing Practices in the United States,", O. Suchsland and G.E. Woodson. *USDA Forest Service Agriculture Handbook*, N. 640, 1980.

5. “The Bauer Method of Preparing Furnishes for the Manufacture of Insulation Board and Hardboard,” C.K. Textor. “Fibreboard and Particleboard,” *Proceedings of International Consultation on Insulationboard, Hardboard and Particleboard*; *1957*; Vol. III; Paper 5.3, Rome: FAO; 1958.

6. “Continuous Acid Hydrolysis Reactors,” Harris Group Inc., Report No. 10600/17, January 22, 2001.

7. “Recommended Materials of Construction,” Harris Group Inc., Report No. 10600/12, Revision 1, January 2, 2001.

APPENDIX A
SPECIFICATIONS FOR REACTOR FABRICATION

TECHNICAL SPECIFICATION 99-10600/03

ACID HYDROLYSIS REACTORS
BATCH DIGESTER ALTERNATIVE

CONFIDENTIAL

PROJECT NO. 99-10600
PROCESS DESIGN AND COST
ESTIMATE OF CRITICAL EQUIPMENT
IN THE BIOMASS TO ETHANOL PROCESS

DATE: OCTOBER 17, 2000

1. GENERAL DESCRIPTION AND SCOPE OF WORK

A series of batch digesters is required for a hydrolysis stage to process hardwood chips before fermentation into ethanol. Laboratory and pilot work dictate a short high-temperature cook. The chips would be preimpregnated with sulfuric acid in a pretreatment system, then charged into the batch digesters for a vapor phase cook. In the digester, the chips would be steamed to reach maximum pressure, held for a set time, then blown to a cyclone steam separator and dropped into a dump chest. A pressure relief step is included for energy conservation and to simplify the blow valve design.

Preliminary design criteria are shown in Table 1.

1.1 Design Basis

The original basis for the digester was to be the Masonite explosion gun built on a larger scale. The Masonite gun was a 10-cu-ft vessel that cycled to a maximum pressure of up to 900 psig, then blew the chips through a specially designed blow valve to defiber the wood. In the current case, defiberization is not a necessary requirement and an alternative digester design has been identified.

In the 1950s a digester was described using 300 psig maximum pressure and with a 150-cu-ft capacity to treat chips before defiberization in a disc refiner. This unit, the Bauer rapid cycle digester, is of similar size and was designed for a similar cycle and operating pressure to that sought in this project. The digester was relieved to 25 to 50 psig before blowing.

1.2 Vendor Scope of Supply

Vendor shall supply a quote for the following equipment per the design conditions listed in Table 1:

- Batch digester
- Motor-operated feed valve
- Motor-operated blow valve
- Motors

The following will be furnished by others:

- Chip pretreatment system
- Structural steel

- Access platforms, ladders, and supports
- Piping and ductwork to and from equipment
- Installation and erection
- Wiring to and from equipment
- Foundations and anchor bolts

Table 1
Preliminary Design Conditions

		Alternative 1A	**Alternative 1B**	**Alternative 2**
Digester size	cu ft	250	250	250
Wood charge	odmt	1.2	1.2	1.2
Typical cycle				
Chip fill	minutes	1	1	1
Close cap	minutes	0.5	0.5	0.5
Steaming	minutes	3	3	3
Hold	minutes	2	2	2
Pressure relief	minutes	1	1	1
Blow	minutes	1	1	1
Open cap	minutes	0.5	0.5	0.5
Total cycle time	minutes	8	8	8
Maximum pressure	psig	250	250	150
	bar	17	17	10
Pressure at blow	psig	50	50	50
Maximum temperature	ºC	200	200	183
	ºF	392	392	360
Digester size, ID *				
Diameter	ft	5.0	5.0	5.0
Height	ft	15	15	15
Materials of construction		nickel alloy 825 or Hastalloy C2000	acid brick	316L stainless

* Nominal dimensions, assuming 20% free space. Alternative dimensions that would facilitate chip discharge are acceptable.

2. DESIGN CONDITIONS

Vendor is requested to provide quotes on the process operating conditions listed in Table 1. Information has been provided for the suggested metallurgy.

3. MATERIALS OF CONSTRUCTION

The sulfuric acid concentrations to be used are in the 0.05% to 2.0% range. These concentrations are very corrosive to steel and will require either an acid-resistant brick lining or a clad metal. Investigations by Harris Group have indicated that nickel alloy 825 or Hastalloy C2000 has acceptable corrosion resistance under the conditions required.

Due to the high cost of these materials, a brick-lined vessel may be more economical. The small size and rapid temperature and pressure cycling of the process may cause stress-related problems and these factors should be taken into consideration.

For the alternative hydrolysis without sulfuric acid, 316L stainless steel is an acceptable material.

4. SPECIFICATIONS

4.1 Codes and Standards

All equipment shall be designed and constructed in accordance with the latest editions of applicable tank codes or standards. Any conflict between standards shall be referred to the Purchaser who shall determine which standard shall govern.

Reference to the standards of any technical society, organization, or association, or to the laws, ordinances, or codes of governmental authorities shall mean the latest standard, code, or specification adopted, published, and effective at the date of taking bids unless specifically stated otherwise in this specification or the detailed equipment specifications.

Codes and standards may include, but not be limited to, the following:

AISC American Institute of Steel Construction

ANSI American National Standards Institute

ASME American Society of Mechanical Engineers

ASTM American Society of Testing Materials

AWS American Welding Society
D5. Field Welding of Steel Storage Tanks
ANSI/AWS D1.1 - Structural Welding Code

ISA Instrument Society of America

NEC National Electric Code

NFPA National Fire Protection Association

OSHA Occupational Safety and Health Act

UBC Uniform Building Code

SSPC Steel Structures Painting Council, Steel Structures Painting Manual, Vol. 2

4.2 Detailed Specifications

4.2.1 The equipment shall be of heavy-duty construction suitable for continuous operation. Bearings shall be of the anti-friction type and sized for a long service life. Reduction gear units shall have a Class II or equivalent service rating.

4.2.2 All components of the batch digester and its infeed and its discharge system that may be exposed to feed stock or sulfuric acid shall be fabricated from the suggested metallurgy listed in Table 1 or Purchaser-approved equivalent.

4.2.3 Wearable components shall be designed so they are replaceable.

4.2.4 Bearings shall be regreasable, anti-friction, self-aligning pillow block type. Pillow blocks shall be applied so that forces are directed radially downward into the base so that the housing is under compression. Should shear forces be induced into the housing, manufacturer shall be consulted as to the application and strength of housing. When shear forces are present at the base, the fixed bearing shall be next to the drive end of the shaft. All other bearings shall be the floating type. Bearings other than pillow-block type shall be restricted to use in enclosed, oil-bath type operation (e.g., reducers).

4.2.5 All equipment supplied as part of this specification must meet applicable industrial safety codes.

4.2.6 Design shall include consideration of dust explosion potential and spontaneous ignition potential.

4.2.7 Vendor shall provide reversing motor starter and controls to permit jog forward and reverse functions. Motor and drive shall be designed to accommodate these functions.

4.2.8 Each valve shall be complete with auxiliary hand wheel operator and any necessary limit switches and spring-mounted yoke supports.

4.2.9 All exterior surfaces shall be cleaned of welding slag, burrs, and grease.

4.2.10 Ferrous surfaces that should not be painted and are subject to corrosion shall be coated with rust preventative compound, Houghton Rust Vet 344, Rust-Oleum R-9, or Purchaser-approved equivalent.

4.2.11 All nozzles shall have moisturetight blind flanges attached for shipment of the vessels.

4.2.12 All electrical wiring supplied as a part of the equipment shall meet National Electric Code requirements for installation. All wire, switches, boxes, and other similar wiring devices shall carry an Underwriters' Laboratories approved label.

4.2.13 The equipment shall be designed for Seismic Zone 3.

4.2.14 The exterior design temperature high is 110°F and low is 40°F. Design relative humidity is 20% to 80%.

4.3 Instrumentation and Control

All instrumentation required for proper monitoring and control of feeder, discharge valve, and batch digester functions shall be provided by Vendor.

5. MATERIALS AND EQUIPMENT

Unless specifically provided otherwise in each case, all materials and equipment furnished for permanent installation in the work shall conform to applicable standard specifications and shall be new, unused, and undamaged.

Individual parts shall be manufactured to standard sizes and gages so that replacement parts furnished at any time can be installed in the field.

6. MISCELANEOUS MATERIALS

Miscellaneous materials not otherwise specifically called for shall be furnished by Vendor. These shall include, but not be limited to, the following as it applies to equipment furnished by Vendor.

- Guards for all exposed shafts, couplings, sheaves and belts.
- All nuts, bolts, studs and gaskets between components and equipment furnished by the Vendor.
- Safety equipment to prevent dust explosion and spontaneous ignition, if applicable.

ARS/mlm

File No.: 99-10600.0501

TECHNICAL SPECIFICATION 99-10600/03

ACID HYDROLYSIS REACTORS
BATCH DIGESTER ALTERNATIVE

CONFIDENTIAL

PROJECT NO. 99-10600
PROCESS DESIGN AND COST
ESTIMATE OF CRITICAL EQUIPMENT
IN THE BIOMASS TO ETHANOL PROCESS

DATE: OCTOBER 17, 2000

SPECIAL INSTRUCTIONS

1. Bidder shall provide schematic of proposed equipment.
2. Bidder shall submit proposal in accordance with this specification.
3. Bidder shall state motor hp and rpm required for equipment.
4. Bidder shall include a list of facilities where reactors, similar to the units quoted, are in operation.
5. Bidder shall include weight of proposed digester options.

APPENDIX B
CONVERSATION RECORDS

Conversation Records

Masonite Corporation
Chicago, IL

Contact: Mike McDonald, Technical Manager
Marcus Kuizenga, 630-513-4138

Requested any details available on the Masonite gun. Referred to a USDA publication on the manufacture of fiberboard. Sent partial copy plus original patent. Gives good details of gun. Located original at WTC library.

Information on Masonite gun installations from old Lockwood directories.

Andritz (current owners of Bauer technology)

Contacts: Brad Cort, Technical Manager
Cecil Bail, Engineer

October 24th, 2000: Brad Cort reviewed the digester specifications based on the published Bauer rapid cycle digester. He determined that the company was not interested in supplying such a digester now.

November 1, 2000: Brad located Cecil Bail within the company. Cecil had previous involvement with the rapid cycle digester. We reviewed the design and operation. He had the following comments:

> Only a few were built in the early 1960s; none are now in existence.
>
> The lower cone must have a shallow taper and the taper to the blow valve which should be 10-inch diameter and must be smooth to allow clean blowing of the chip mass.
>
> The working volume should be 75% to 80% of the total volume to aid in clean discharge at the blow.
>
> There were problems with cracking of welds in 316L stainless due to the stresses of the cycle. Carbon steel shell clad with stainless might be better.

Nooter Fabricators
St Louis, MO
314-621-6000

Contact: Kirk Miller, Retired Design Manager, 314-421-7221
Barry Heuer, Chief Metallurgist

Could not be competitive with smaller fabricators in this size range.

RECOR Services Inc.
Vancouver, WA

Contact: Jerry Jones, 360-253-6452

July 24th-October 25th, 2000

RECOR is a division of DIDIER Company of Germany.

Would use a subcontractor for vessel fabrication and do the lining themselves. A 3- to 4-week turnaround for pricing as it has to be reviewed in Germany.

A lining consisting of a layer of bitumen against the steel shell followed by a course of acid brick, then one of carbon brick, would meet the acid-resistant requirement.

Specifications for three alternatives sent August 8th, 2000.

Delay in response due to Jones being involved in an out of office construction project.

October 25th, 2000 response by phone:

The German parent company considers the short cycle and blows would create too much stress in the brick lining causing rapid deterioration under operating conditions. Therefore not willing to bid. (e-mail Mj to LM October 25th, 2000)

Also not willing to undertake the engineering and subcontracting for the alloy vessels as this does not fit their area of operations.

Requested letter stating RECOR's position. Handwritten note received by fax January 15th, 2001 confirming their opinion that a brick lining would not work under the proposed service due to the high cycle rate.

Metso/Valmet/Sunds

Contacts: Jan Nordin, West Coast Representative
Frank Steffes, Pulping Technical Rep

October 27th, 2000 Jan referred me to Frank Steffes

November 13th, 2000: Frank determined that their batch digester group were not interested due to the small size of the job. Another division may be interested and the specifications were being forwarded to them.

January Division turned down the job. Contact regarding the blow valve was established, Randy Taylor 360-253-9120.

Stebbins Engineering

Contact: Linda Harding, Manager Seattle Office

November 11th, 2000: Stebbins provide services to line digesters. They are not interested in the fabrication of a digester as this would be contracted out.

They believe that a small vessel could be lined using bitumen, acid brick and carbon brick. This is used in sulfite digesters.

Price quotation

CBI-Walker
Norcross, GA

Contact: Larry Hinckle 770-446-0036

CBI build about half the batch digesters constructed in the US. Nooter did the rest.

They do on-site fabrication. The biomass digester is of a size that it would be constructed in a shop and shipped. They cannot compete for this type of fabrication.

GL&D (previously Beloit Pulping Div)

Contact: Manfred Durek, West Coast Manager

Manfred referred specification to head office. Response negative.

Figure 1

<u>Masonite Gun</u>

Reference 4

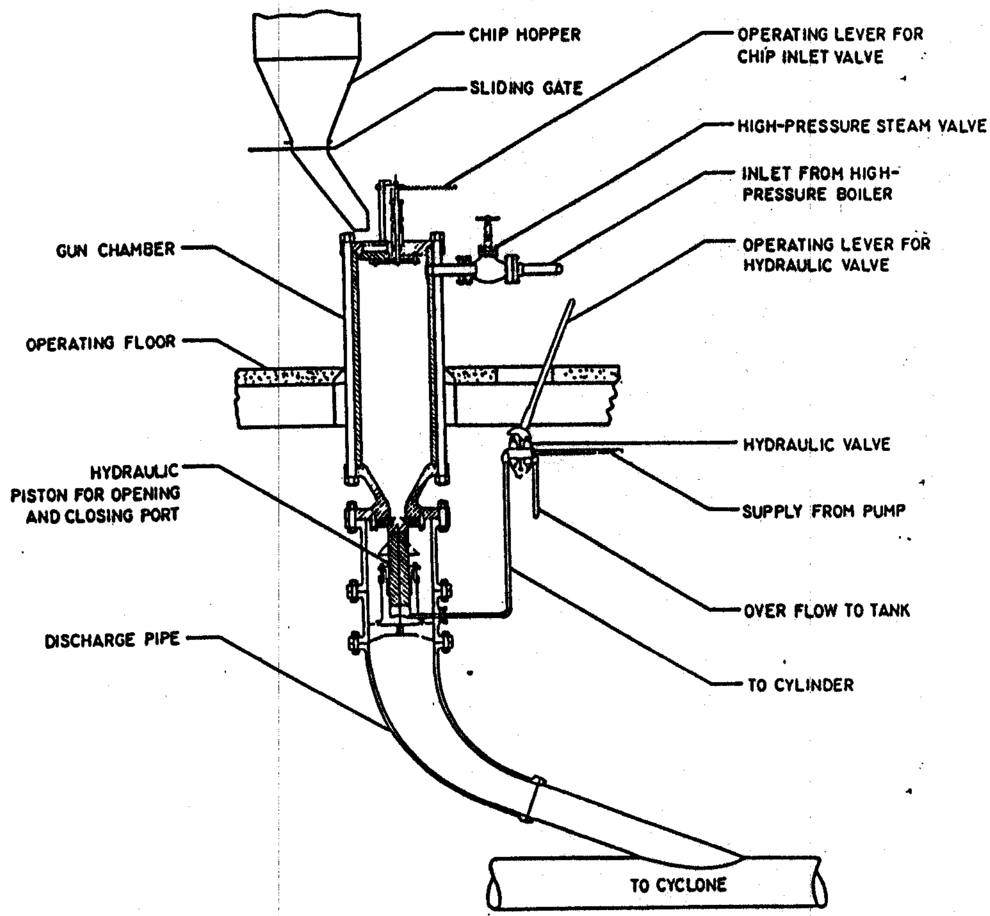


Figure 2

<u>Bauer Rapid Cycle Digester</u>

Reference 4

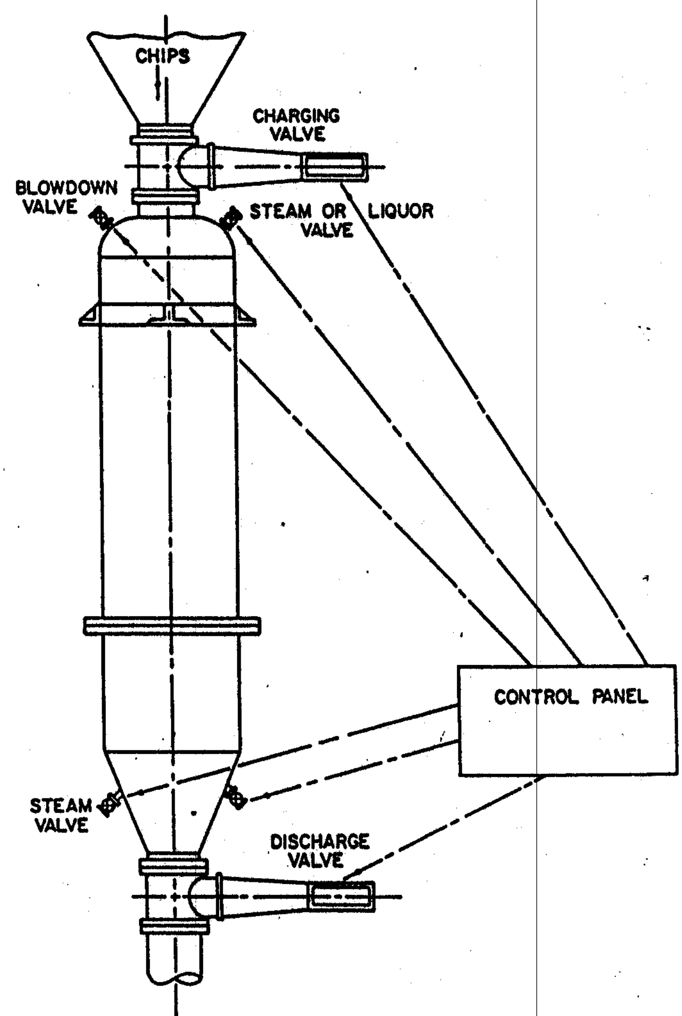
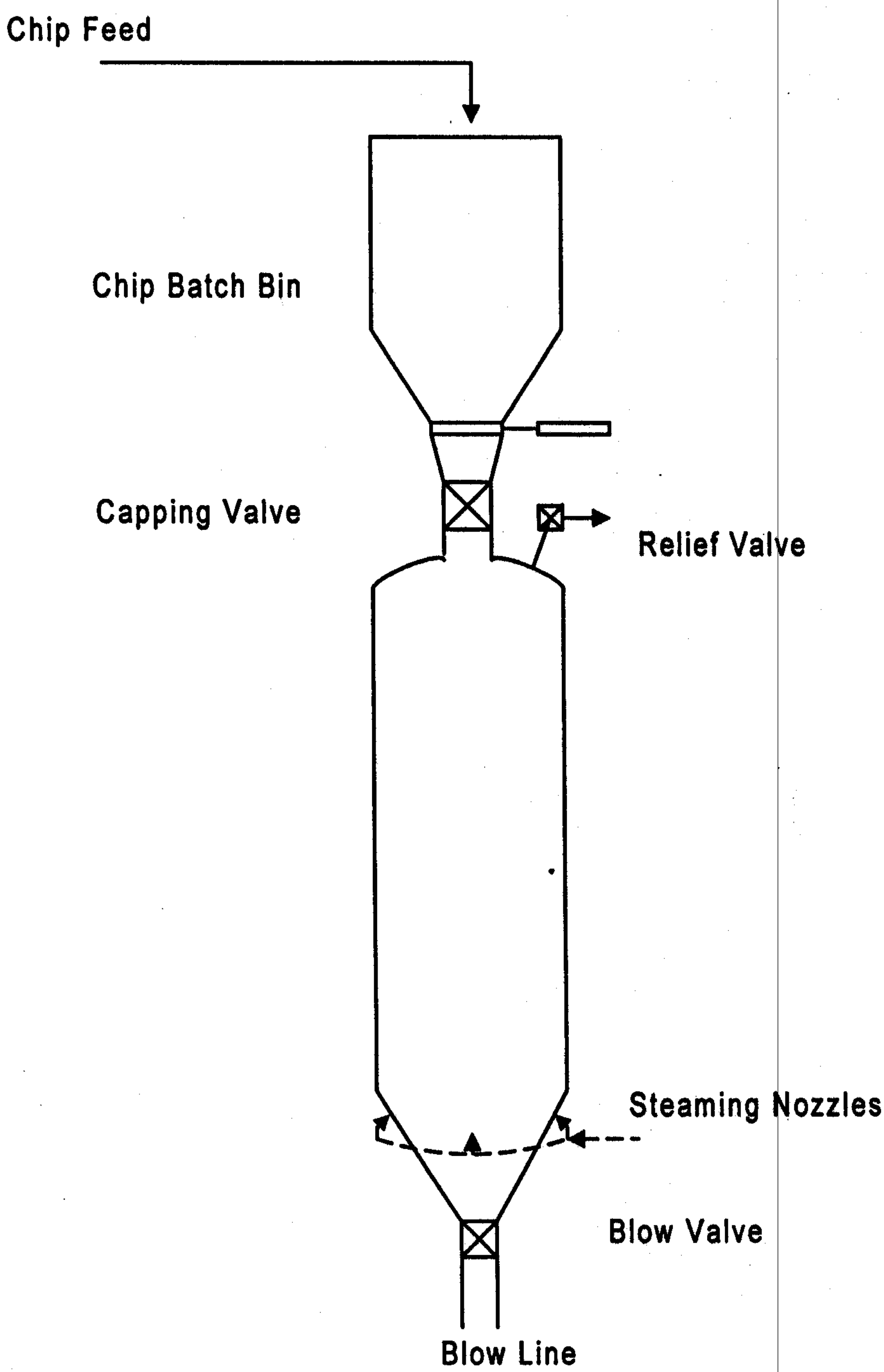


Figure 88—*Automatic Bauer rapid cycle digester (Textor 1958).*

Figure 3

Batch Biomass Hydrolysis Digester



Chip Bin--5' diam x 15'

Capping Valve 18" ID

Digester--
Main section--4' diam. x 16

Blow valve--10" ID

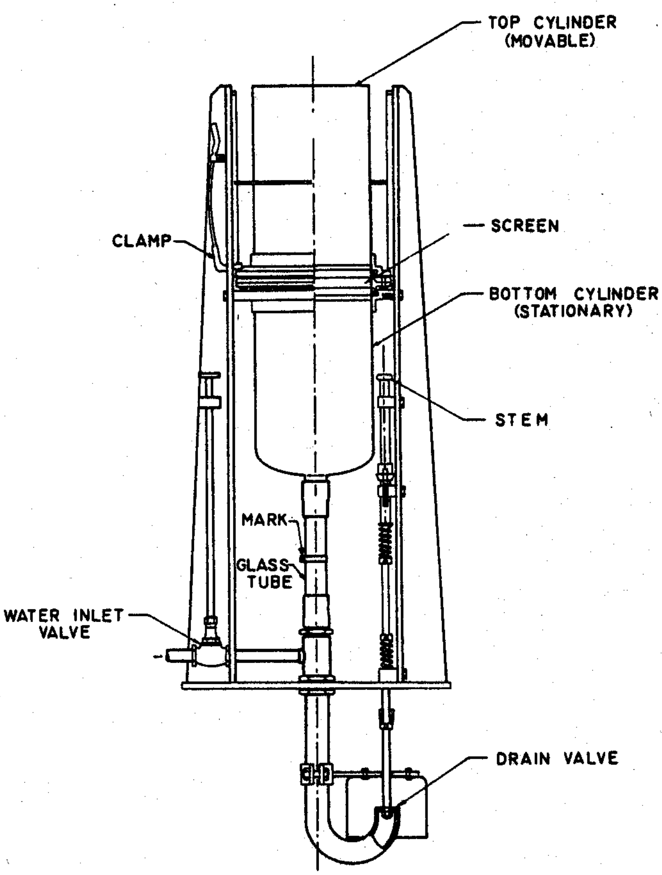


Figure 78—*Defibrator pulp freeness tester (Sunds Defibrator).*

processing characteristics. Freeness cannot always be correlated with actual water drainage characteristics on the forming machine (D'A Clark 1970). Rather, relationships between measured freeness and processing characteristics must be determined in each case in the mill. Then the freeness measurement is an important quality control device.

In general, the larger the total surface area of a quantity of pulp, the slower the pulp will be. The pulp surface area can be increased by more extensive refining (more energy per ton of pulp) causing a squeezing, crushing, and **fibrillation** (broomlike appearance of fiber ends) of the fibers. This fibrillation is important for the promotion of hydrogen bonding in paper. Most fiberboards do not rely on hydrogen bonding for their strength, but, because of their much thicker mats, they require fast draining stock. A high degree of freeness is therefore one of the most important characteristics of fiberboard pulp. Insulation boards do rely on hydrogen bonding and require slower pulps. In dry fiberboard processes, freeness is meaningless and is not measured.

The Masonite Pulping Process

General

In the Masonite pulping process, steam provides both the conditions under which the natural fiber bond is softened and the force that finally breaks that bond. In all other mechanical pulping processes, fibers are separated by the action of abrading or cutting tools.

The Masonite gun and its operation

The Masonite gun—so called because of the explosive nature of the defiberizing phase—is shown in cross section in figure 79. This drawing is taken from Mason's article on pulp and paper from steam-exploded wood, written in 1927 (Mason 1927). The appearance and size of the gun have not changed much over the years, although its operation today is automated (figs. 80, 81). The Masonite gun is used exclusively by the Masonite Corporation.

The gun is a pressure vessel with an inside diameter of about 20 in, a height of about 5 ft, and a capacity of about 10 ft^3, (about 0.1 ton) of green wood chips. At the tapered bottom end, the vessel is equipped with a slotted port and a quick-opening hydraulic valve. An inlet valve at the top is designed to receive the chips from a hopper. Steam is admitted through a high-pressure steam valve. The sequence of operation is as follows (Boehm 1930):

1) Gun is loaded with green chips through the port on the top.
2) Chip inlet valve is tightly closed.
3) Low-pressure steam (350 lb/in^2—just over 430 °F) is admitted immediately. This brings the chips to a temperature of about 375 °F.
4) The chips remain at 375 °F for 30 to 40 s.
5) High-pressure steam is admitted and the gun pressure is elevated within about 2 to 3 s to 1,000 lb/in^2, equivalent to a temperature of about 540 °F.
6) The chips remain at this pressure for about 5 s.
7) The hydraulic discharge valve is opened.
8) The chips explode due to the pressure differential and at the same time are forced by the expanding steam through the slotted bottom port plate where they are shredded into a mass of fiber bundles.
9) Steam and fibers are separated in a cyclone.

A typical time-pressure diagram for the Masonite gun operation is illustrated in figure 82.

The program of steam pressurization may vary (Spalt 1977):

Steam pressure may be raised steadily until discharge

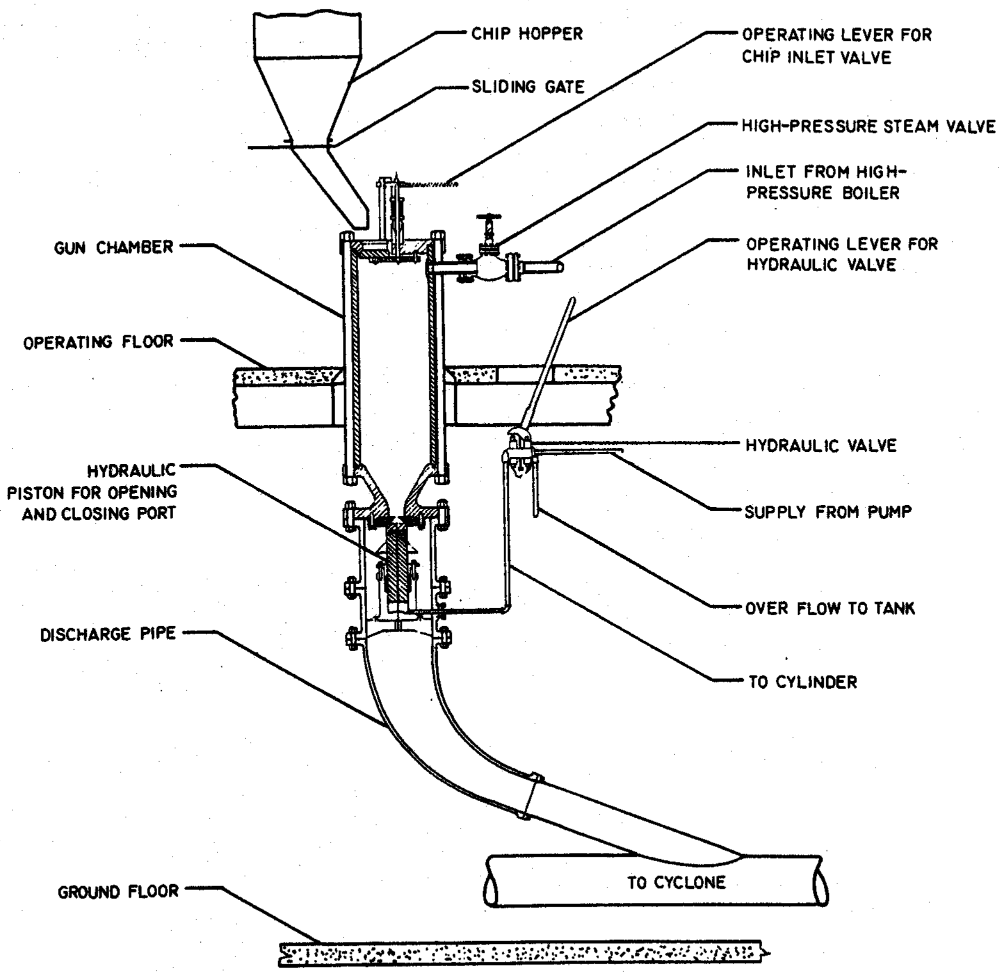


Figure 79—*Cross section of Masonite gun (Mason 1927).*

Figure 80—*Series of Masonite guns (Masonite Corp.).*

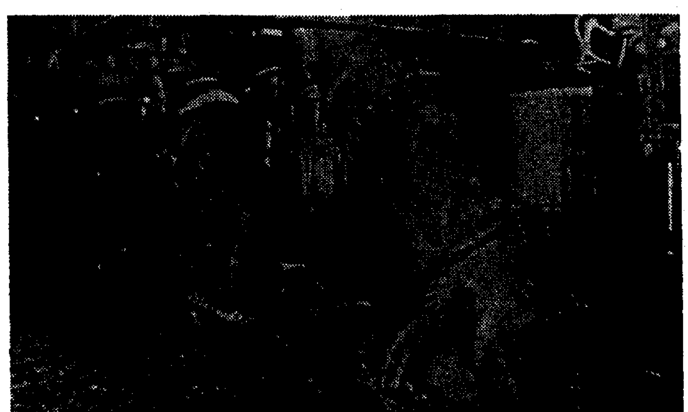


Figure 81—*Discharge tubes of Masonite guns (Masonite Corp.).*

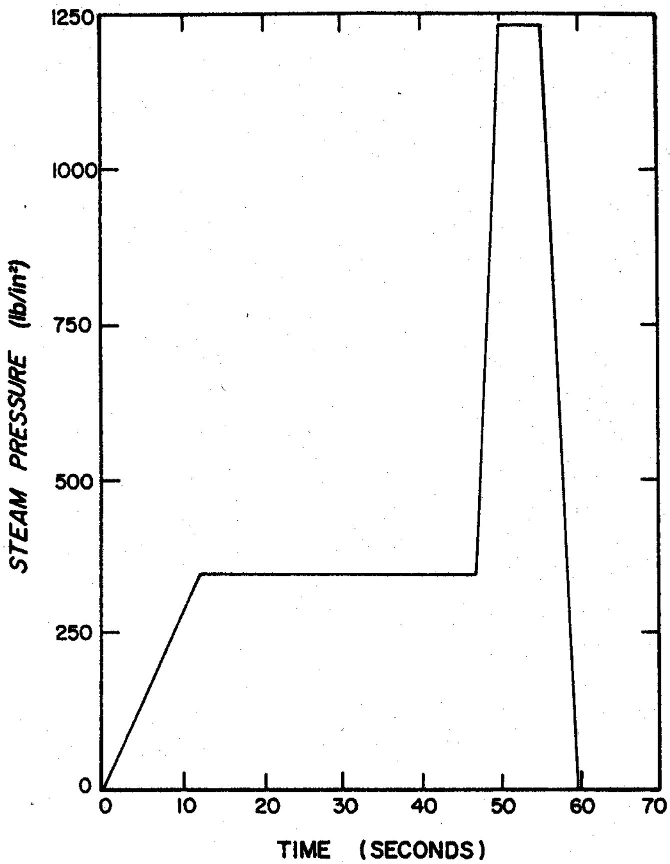


Figure 82—*Typical Masonite gun cycle.*

to the atmosphere at target pressure. Or, steam pressure may be admitted at a prescribed rate until a target pressure is attained, held for a prescribed time, and discharged. Another version uses controlled rate of steam pressurization to target pressure, hold at pressure up to 90 seconds, and raise rapidly to a higher pressure (shooting pressure) and discharge. After separation in cyclone, pulp is diluted and conveyed to secondary refiners.

Effect of gun cycle on wood chip

During the severe treatment of the wood chips, important structural and chemical changes occur:

1) Part of the wood substance is dissolved.
2) The lignin bond is chemically and physically weakened, thus allowing relatively easy separation of fibers upon decompression.

The dissolution of part of the wood substance is due to hydrolysis of the hemicellulose under the catalytic action of acetic acid. The hemicellulose breaks down to sugars (hexoses and pentoses), which are water soluble and are removed from the pulp by washing. The degree of hydrolysis and the extent of wood losses can be controlled by modifying the gun cycle (Boehm 1944). The catalyzing effect of acetic acid, which is believed to be generated by cleavage of acetyl groups of hemicellulose at steam pressures between 300 and 400 lb/in^2 is illustrated as a sudden rise in the hot water extractability (fig. 83). The effect of preheating time on pulp yield is shown for various temperatures in figure 84.

Pulp yields of the Masonite process have been reported as low as 65 to 70 percent, and more recently as between 80 and 90 percent. Very early Masonite yields were less than 50 percent. Yield figures are influenced not only by the temperature–time gun cycle, but also by such variables as species, specific gravity, growth factors, moisture content, etc. The Masonite process, originally based on southern pine, is now applied mainly to hardwoods in the Masonite plant at Laurel, MS. Masonite's other wet hardboard plant in Ukiah, CA, is based on softwoods. Because softwoods and hardwoods require different gun cycles, when both woods are used in the same mill they are pulped separately and then mixed.

Masonite pulp characteristics

Masonite pulp is dark in color due to thermal degradation. Jack pine pulp (Masonite) studied by Koran (1970) consisted of 60 percent fiber bundles and 40 percent individual fibers and fiber fragments. The fibers appeared relatively stiff and showed little collapse. Their surfaces were very smooth and were enveloped by a continuous primary wall network, heavily encrusted with lignin and in many areas covered by thick layers of middle lamella substance (Koran 1970). This indicates that the fiber separation occurred in the lignin-rich middle lamella or in the primary wall rather than in the lignin-poor and cellulose-rich secondary wall. Early investigators of the Masonite process recognized an "activation" of the lignin, a condition suitable for reexerting its bonding power in the hotpress (Boehm 1944).

Masonite fibers are not "fibrillated," that is, they do not have the ribbonlike appendages that give the fiber the broomlike ends essential for the development of hydrogen bonding in paper. Masonite pulp will not produce this fibrillation even with further refining and is therefore unsuited for paper manufacture. It is, however, for the same reason a very free pulp that drains water fast, an important characteristic in the manufacture of wet-formed hardboard.

Because of the presence in the pulp of acetic and formic acids, the pH of Masonite stock is low, between 3.0 and 4.0.

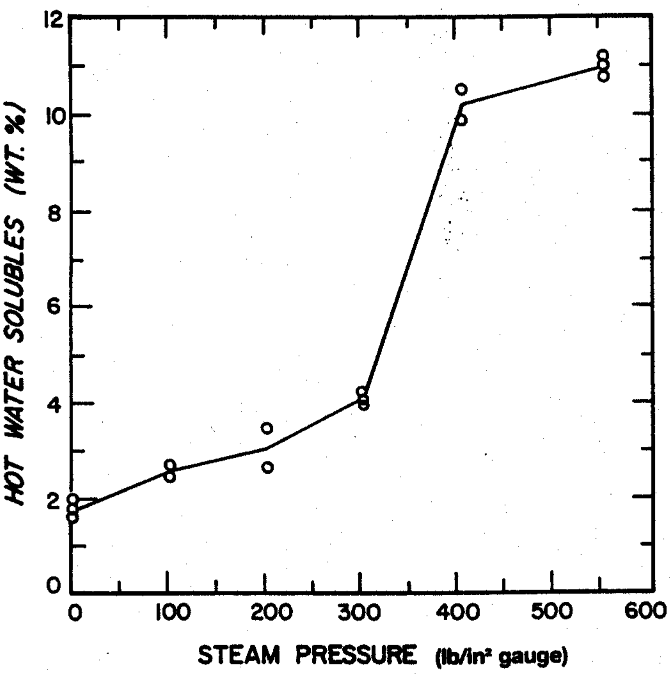


Figure 83—*Hot-water extractability of wood chips as a function of saturated steam pressure used in the preheat segment of the digesting operation (Spalt 1977).*

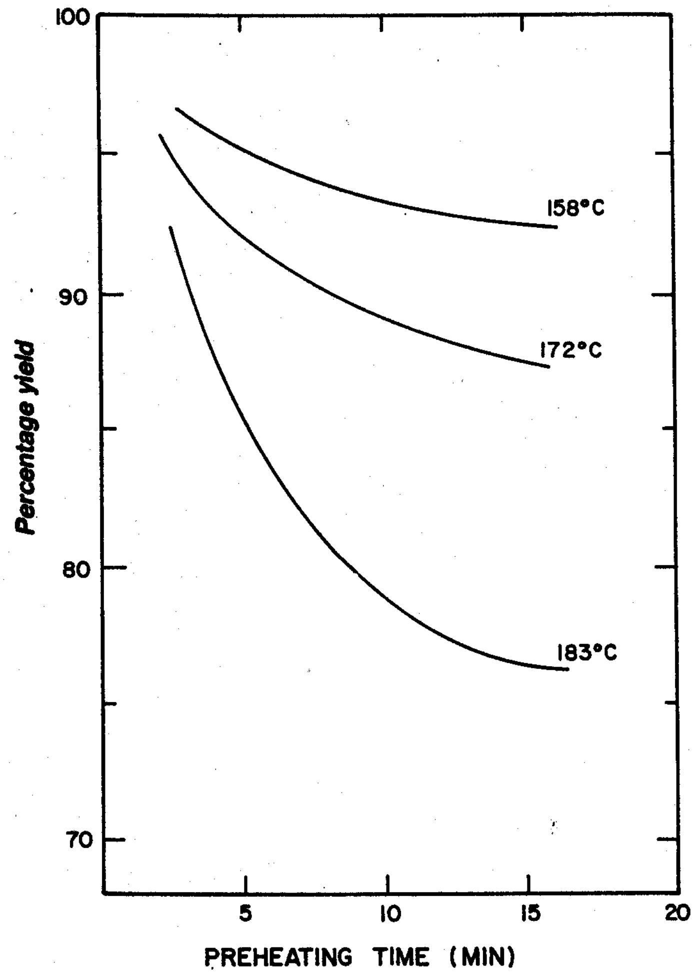


Figure 84—*Effect of preheating time and temperature on pulp yield (EPA 1973).*

The Masonite pulping method, in terms of the pulp quantity it produces, is still—at least in the United States—a major pulping method. However, it is doubtful that any more Masonite guns will be installed in the future. Low yield and relatively high energy requirements will cause their gradual replacement by disk refiners.

Disk Refining

General

The significant feature of the disk refining process is the mechanical shearing, cutting, squeezing, and abrading action to which the pulp chips are exposed as they are being forced through the narrow gap between two profiled disks.

Disk refining was introduced in the paper industry as a substitute for stone grinding in the 1920's. It has obvious advantages over stone grinding, such as the possibility of using wood chips and wastes rather than just roundwood, the possibility of using hardwoods, and generally easier raw material handling. Disk refining allows a variety of controlled pretreatments such as water soaking, steam cooking, and chemical treatments. Disk-refined pulp is generally of higher quality than groundwood.

In the fiberboard industry, disk refiners were first introduced by the U.S. Gypsum Company at Greenville, MS, when it became desirable to utilize hardwoods that could not be ground on stone grinders. Today, most fiberboard pulp is produced by disk refiners.

Types of disk refiners

There are two different dynamic principles in disk refiner design: the single disk and the double disk. Actually, both have two disks, but in the **single-disk** machine only one revolves, the other is stationary (fig. 85). In the **double-disk** machine both disks revolve at the same speed but in opposite directions (fig. 86). The actual profiled cutting elements (plates) are ring segments bolted to a disk or housing, each constituting a third or a sixth of the full circle. These plates are made of wear- and corrosion-resistant alloyed steel castings and are supplied in various profiles, depending on the application. A selection of plate profiles as used in the fiberboard industry is shown in figure 87 (Bauer).

unit will be set in motion by the revolving disk, will roll on the stationary plate, and will travel in a spiral path from the center to the periphery. It will be subject to two centrifugal forces; the rapid rolling will tend to "explode" the ball, while the spiral travel will work to accelerate discharge of the ball from the machine. On the other hand, a ball similarly placed between the plates of a double revolving disk unit, will receive the same but opposite impetus from each plate; it will roll rapidly but will not travel outwardly as long as it is in contact with both plates, except for other forces such as gravity, or the feeding of additional material. The only centrifugal force acting on a ball under such conditions is that tending to explode it.

Disk refiners are also classed as either primary or secondary refiners. Most of the breakdown of the chip occurs in the **primary refiner**, requiring high energy input. Secondary refining requires only about one-tenth or less of the total pulping energy. Primary refiners are thus high-powered machines, whereas **secondary refiners** are smaller, with lower power. They are sometimes called "pump through" machines.

Finally, there is the important distinction between atmospheric and pressurized refiners. **Pressurized refiners** are capable of maintaining, in the refiner housing and particularly at the refining zone, a steam atmosphere at elevated pressure levels. This has important technological consequences, to be discussed later in this chapter. **Atmospheric refiners** have no such capabilities, but, when handling liquid stock, may develop hydraulic pressures as high as 100 lb/in².

Atmospheric disk refining

Most atmospheric refining takes advantage of the beneficial effects of thermal treatments of the pulp chips on pulp properties. These treatments are applied to the chips in either batch type or continuous digesters.

Textor (1948) lists the following treatment categories:

a) No treatment—green chips
b) Steaming or water soaking—atmospheric pressure, temperature.
c) Steaming or water cooking—elevated pressure, temperature.

No treatment produces a pulp that is very similar to groundwood. The middle lamella is not the usual plane of failure, and the method produces a relatively slow pulp with a large portion of broken fibers and fiber bundles. It is used in dry processes not greatly dependent on the lignin bond, where freeness is not a problem, and in wet processes where surface quality requirements are not very critical. The pulping of untreated chips is energy intensive. The advantage of untreated chips is that they produce maximal yield and minimal biochemical oxygen demand (BOD) loading of process water (wet process). The second type of pretreatment produces slight improvements in the pulp. The fibers are more pliable, fewer are broken, and better felting and a stronger mat result.

The third pretreatment—steaming or water cooking—produces important changes in the wood structure. Depending on the severity of the treatment, hydrolytic breakdown of hemicellulose and lignin reduces yield and increases the BOD loading of the process water **(white water)**. The color of the chips changes to brown. Power consumption in the refining process is reduced, and the pulp is strong and pliable, improving the quality of wet formed S1S and S2S fiberboard.

Figure 88 (Textor 1958) shows an automatic Bauer rapid cycle digester for steam pretreatment of pulp chips at elevated pressures. The digester is a pressure vessel made of corrosion-resistant material, about 3 ft in diameter and about 20 ft tall, holding about 120 ft³ of chips, designed for pressures up to 300 lb/in². Chip input at the top and discharge at the bottom are controlled by large-diameter hydraulically operated valves. The sequence of operation follows:

1) With bottom valve closed and top valve open the digester is filled with green chips.
2) With both top and bottom valves closed, bottom steam valve and vent valve are opened. (This fills the digester with steam and removes the air.)
3) Vent valve is closed and steam pressure built up to desired level.
4) After maintaining steam pressure for desired time, pressure is reduced by opening vent valve.
5) When pressure has dropped to about 25 to 50 lb/in², chips are blown into the chip bin by opening bottom valve.
6) Steam escapes into atmosphere through large-diameter blow stacks.
7) Cooked chips are conveyed to primary refiners.

A continuous digester is shown in figure 89. The horizontal pressure cylinder, made in various sizes up to a 40-in diameter and 40-ft length, is equipped with a screw conveyer. The **dwell time** (cycle time) can be controlled by a variable speed drive that adjusts the rate at which the chips are moved laterally. The cylinder is sealed at both ends by rotary valves that charge and discharge chips into and from the digester at a constant rate. Steam is admitted to the cylinder, and the cooking conditions are maintained continuously. (See also Atchison and Agronin 1958.)

Cooking conditions depend greatly on wood species. Softwoods require longer cycles than hardwoods. The more severe the cooking conditions, the greater are the hydrolytic loses, the lower the yield, and the greater the contamination of white water with biodegradable materials. On the other hand, more severe cooking conditions result in cleaner fiber separation and availability of more lignin for bonding. The tendency in the industry is to reduce steam pressures in the interest of greater yields and lower white water BOD levels.

A northern wet-process hardboard mill reports the following practical cooking cycles in rapid cycle digesters (Eustis 1980):

Product type	Species	Cooking cycle
S2S	Poplar	180 lb/in² steam pressure; 2-min treating time
S1S	50:50 oak-birch	150 lb/in² steam pressure; 30-s treating time

Should the species composition of the S1S furnish change so that the oak component exceeds 60 percent of the total, then the cooking cycle must be shortened. Should the oak component drop to less than 40 percent, the cooking cycle must be lengthened. With straight pine, the cook would have to exceed 2 min.

A southern insulation board mill reports a cooking cycle of 6 min at 190 lb/in² steam pressure for pine chips.

In winter, allowances must be made in the cooking cycle for frozen wood. This is done by increasing the vent cycle from 15 s in the summertime to at least 1 min in the winter. This allows the ice to melt before steam pressure is applied (Eustis 1980).

A northern hardboard siding mill produces most of its furnish on atmospheric refiners without cooking.

Feeding of refiners. For consistency in output quality, refiners should be charged to run at full load. This can best be accomplished with single- or twin-screw feeders or coaxial feeders that force-feed the treated chips into the refiners at a constant and controllable rate (figs. 90, 91). Such feed systems require an oversupply of chips at the refiners in order to avoid the possibility of shortfalls. Surplus chips are returned to the chip bins (fig. 92).

Refiner variables. The goal of the refiner operation is the production of a pulp ideally suited for the manufacture of a particular board product. This desired pulp quality is difficult to define in simple terms. It includes freeness, fiber length distribution, springiness, and other quality elements that may only be expressed in terms of final product properties. Neither are these quality elements controlled entirely by refining variables. They are also influenced and limited by raw material qualities such as species and by the cooking conditions.

The dominating operation variable is the throughput rate, which influences the specific energy, i.e., the energy required per unit weight of pulp produced. Figure 93 illustrates the interrelationship between this operation variable and various pulp and sheet properties, of which the freeness or drainage time is the most important for fiberboard manufacture.

In practical operations—given a certain raw material and a certain pretreatment—the freeness of the stock on the forming machine is used as the primary indicator for controlling refiner operation. These freeness re-

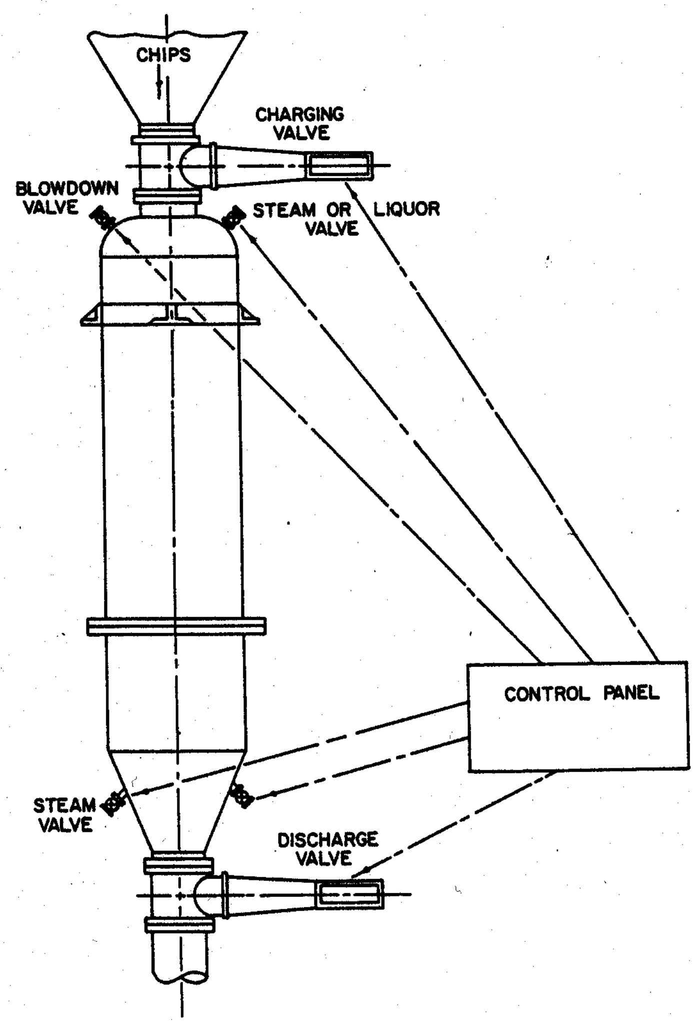


Figure 88—*Automatic Bauer rapid cycle digester (Textor 1958).*