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# THE MADISON WOOD-SUGAR PROCESS

June 1946



No. R1617



UNITED STATES DEPARTMENT OF AGRICULTURE  
FOREST SERVICE  
FOREST PRODUCTS LABORATORY  
Madison, Wisconsin  
In Cooperation with the University of Wisconsin

# THE MADISON WOOD-SUGAR PROCESS<sup>1</sup>

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## Abstract

A process, known as the Madison wood-sugar process, has been developed by the Forest Products Laboratory for hydrolyzing mixtures of wood waste consisting of chipped slabs and edgings, sawdust, and shavings, with 0.5 to 0.6 percent sulfuric acid at temperatures of 150° to 180° C. by allowing the dilute acid to flow continuously through the charge of wood.

Compared with the German Scholler process, hydrolysis was accomplished in less time because the sugars produced by the hydrolysis were removed more rapidly. Heating was at a lower rate and more efficient use could be made of the heat given off by the liquors being removed from the hydrolyzer, resulting in a lower steam requirement. Decomposition was less because the sugars were in contact with the acid for a shorter period of time and, consequently, yields of sugar and alcohol were higher. Fewer byproducts inhibitory to fermentation were produced, resulting in more rapid fermentations. Life of valves and other equipment was increased because they were set once for the run and not changed until the end of the run. The sugar produced in 2.8 hours from a ton of dry, bark-free Douglas-fir wood waste yielded 64.5 gallons of 95 percent alcohol as compared to 3.2 hours for 58 gallons by the rapid-cycle method developed earlier, and 13 to 20 hours for 55 gallons by the Scholler process as practiced in Germany.

These new findings indicate that the estimated capacity of the wood-hydrolysis plant being built at Springfield, Oregon, may be increased from 4,100,000 gallons per year to 5,950,000 gallons per year.

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<sup>1</sup>Presented before the American Chemical Society, Atlantic City, N. J., April 8-11, 1946.

<sup>2</sup>Maintained at Madison 5, Wis., in cooperation with the University of Wisconsin.

## Introduction

Previously reported work (4, 7, 15, 33)<sup>3</sup> on wood saccharification has shown that many of the steps in the process described by Scholler (1-3, 5, 6, 9-14, 16, 20, 32) are unnecessary and detrimental, and are responsible for making the German Scholler process unsuited for use in the United States. The batch process, as used by Scholler for the treatment of the charge of wood in the hydrolyzer, is responsible for the long periods of time required (16 to 20 hours), for low concentrations of reducing sugars, and for excessive consumption of chemicals. The steaming and rest periods between batches of acid promote the decomposition of sugar (17), cause a great deal of unnecessary manipulation of controls, and contribute to a short life for valves and other essential parts of the plant. This report describes a new short process which includes (1) a procedure for charging the digester; (2) a method of automatically controlled continuous addition of the acid at the top of the digester; (3) controlled removal of sugar solution from the bottom; (4) controlled hydrolysis to avoid decomposition and lignin plugs; (5) flashing the solution to a definite pressure so that methanol and furfural produced in the process may be recovered and excess steam may be used for heating of water; (6) neutralizing automatically under pressure; (7) filtering under pressure to remove calcium sulfate; (8) flash cooling of the sugar solution; and (9) filtering again to remove organic precipitate that separates on cooling.

## Pilot-plant Equipment

The equipment, shown diagrammatically in figure 1, consists of a hog chipper for converting wood waste to the proper size for hydrolysis; elevating equipment; a triplex pump for water (capacity variable from 2 to 10 gallons per minute); and acid pump (capacity variable from 0.2 to 4 gallons per hour); a switch, on the valve that opens the line to the hydrolyzer, which controls both pumps; a water heater consisting of a jet heater for blowing steam into the water; a jet in the water line for introducing acid; two openings in the top of the digester for introducing acid liquor; a silicon bronze digester 23 inches in inside diameter (capacity 27 cubic feet) fitted with a reducing cone at the top and a reducing cone and filter screen at the bottom; a flash tank; three receiving tanks fitted with mixers; a lignin receiver; a neutralizing kettle; and storage tanks.

## Analysis

Analytical values were determined by the methods reported upon previously by the Forest Products Laboratory (4, 18, 19).

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<sup>3</sup>Underlined numbers in parentheses refer to Literature Cited at the end of this report.

### The Process

Chipping or hogging is an important part of the process. Particles should be large enough so that flow of dilute acid down through the charge is uniform and rapid, but also small enough so that diffusion of the acid into the chip and of the sugar out of the chip is rapid. It was found that Douglas-fir wood-waste mixtures, containing 25 to 30 percent shavings, 25 to 30 percent sawdust, and 40 to 50 percent slabs and edgings, hogged so that particles were between 1/4 and 1 inch long, were satisfactory. The hogged wood contained 35 to 50 percent bark. A hog chipper provided satisfactory material when the larger sizes were screened out and sent through again. Green wood waste containing 30 to 50 percent of its weight as moisture appeared more satisfactory than dry material because infusion of acid was more rapid.

Charging of the digester had to be carried out so that the wood waste was evenly distributed in respect to fine and coarse material, was uniformly packed, and was of such a density that full use of the acid as a hydrolyzing and extracting medium was reached and so that plugging of the digester did not result. Variations in the amount of bark made possible variations in the extent of packing of the charge. Because of the corky nature of bark, charges with large amounts of bark could be packed more heavily into the digester without plugging it. It proved helpful but not essential to place some coarse material on the bottom of the digester to provide a bed for easy flow of the sugar solution through the filtering screen at the bottom of the digester. These conditions were attained when a charge of mixed wood waste was allowed to flow into the heated hydrolyzer until completely full, after which a quick-opening flange cover was put in place and high-pressure steam (150 pounds per square inch) was applied rapidly on top of the charge, with vents open at the bottom until a gage at the top of the digester showed a pressure of 10 pounds. The steam valve was then closed and the steam allowed to flow through the charge until no pressure showed on the gage. The cover was then removed, more of the wood-waste mixture added, and the packing with steam repeated. Charges of 400 to 500 pounds on a dry basis with 25 to 35 percent of bark were introduced under these conditions. The heavier charges were used when the largest amount of bark was present. Most of the air in the chips was removed, and some heating resulted, as the steam passed over the chips. In order to remove more air and to continue the heating, a top vent was opened and steam was introduced at the bottom of the digester. When steam flowed from the top vent, the vent was closed and the steam was allowed to flow into the digester until a pressure of 50 pounds was reached.

Dilute acid at a temperature of 150° C. was introduced into the heated digester in such concentrations that, by the time an amount of dilute acid equivalent to one-half the dry weight of the charge had been introduced, the acid concentration of all the water present would be 0.5 to 0.6 percent. A charge of wood waste containing 45 percent of its weight as moisture, after being packed and heated with steam at 50 pounds per square inch, contained approximately 600 pounds of moisture and therefore required 200 pounds of 2.0 percent sulfuric acid to bring the concentration to 0.5 percent.

After this stronger acid had been introduced, sufficient heated sulfuric acid of 0.5 to 0.6 percent concentration was introduced to bring the ratio of total dilute acid to dry wood substance to about 3 parts acid and 1 part wood substance. Under one set of conditions, this acid was introduced rapidly, so as to flood the charge, and then allowed to digest for approximately 20 minutes. Under another set of conditions, the acid was pumped in at the rate of 20 pounds per minute.

Following this initial charge, heated acid (concentration 0.5 to 0.6 percent) was pumped in continuously at a rate of 20 pounds per minute. The temperature of the incoming acid was adjusted by an automatic temperature controller so that it was increased approximately 5° C. for each 10-minute period until 185° C. was reached; the run was continued at that temperature until completed. This procedure was also compared with the batch procedure for introducing acid used in previous runs (7).

While the continuous pumping was in progress, a flow controller in the acid-sugar-solution line was opened so that 20 to 25 pounds of the solution of acid and sugar were removed per minute.

The continuous introduction of acid and continuous removal of sugar solution provided a means of rapid hydrolysis and removal of the solution. Initial concentrations of reducing sugar were as high as 10 percent. Concentrations decreased as the hydrolysis continued. After about 2 hours of continuous pumping, the concentration fell to about 1 percent, and at this point the introduction of acid was stopped. Sugar solution was removed as long as it flowed freely from the hydrolyzer. In most cases it continued to flow for about 15 minutes, after which a large valve in the bottom of the digester was opened to discharge the lignin into a lignin receiver.

The sugar solution being withdrawn from the hydrolyzer was passed into an expansion chamber of "flash tank" to release the steam and drop the pressure to about 30 pounds per square inch. The drop in pressure was accomplished by a pressure-regulating relief valve which allowed the steam and the vapors of methanol and furfural to pass through a heat exchanger or condenser, in which they gave up heat which was used to heat the water for the dilute acid.

From the flash tank the sugar solution flowed continuously under a pressure of 30 pounds per square inch to a pressure-neutralizing tank (fig. 2) at the rate of 16 to 20 pounds per minute. When approximately 100 pounds of solution had flowed into the tank, the automatic pH controller was started, lime being thereby introduced under air pressure from a lime tank through a proportioning valve. The controller was actuated by a stream of liquid, which was removed from the neutralizing tank and flashed to atmospheric pressure and then allowed to flow over the electrodes in a specially designed cell. The amount of solution required was approximately 100 cubic centimeters per minute. This sugar solution was collected and introduced in the neutralizing kettle prior to the next run. When the pH of the solution in the neutralizing kettle had reached the desired value, a valve to the filter was opened, allowing the same amount of solution to be

removed as introduced. Variations in pH were usually less than 0.1 pH units during the neutralization of the sugar solution for a run requiring about 3 hours.

Attempts were made to neutralize the sugar solution continuously in a pipe line at atmospheric pressure without the use of a holding tank. The lag in the neutralization with lime was too great to permit satisfactory operation of the pH controller. Tests with sodium hydroxide gave satisfactory operation.

Neutralization of the sugar solution under pressure in batches was carried out satisfactorily with the same equipment used for continuous neutralization. Such batch neutralization, however, required either the use of a holding tank to store the solution under pressure or the flashing of the acid-sugar solution to atmospheric pressure before storage, followed by reheating of the solution before it could be neutralized and filtered.

The calcium sulfate, which had separated from the solution under pressure, was removed by passing the solution while under pressure through a steam-jacketed leaf filter. The sulfate content, which would have been 2,100 parts per million at 100° C. and atmospheric pressure, was reduced to an average of about 650 parts per million by neutralizing and filtering it under a steam pressure of 30 pounds per square inch. This low value for calcium is expected to aid greatly in preventing scale formation in the stills during the alcohol distillation.

After being filtered under pressure, the neutralized sugar solutions were cooled to a temperature of 30° C. by flashing. On cooling, a brown precipitate separated from the solution. When this precipitate was removed, the solution was a clear amber color and contained approximately 5 percent reducing sugar.

The procedure described as the "Madison Wood-sugar Process" was used to hydrolyze the carbohydrate portion of Douglas-fir wood waste from saw-mills operating in the Eugene, Oregon, area. Representative samples of bark, bark-free hogged slabs, hogged mill-run slabs and edgings, shavings, sawdust, and hogged mill waste from which the best slabs had been removed were analyzed for bark content, potential sugar content, and potential fermentable sugar content, and then subjected to the pilot-plant batch hydrolysis procedure described in previous Forest Products Laboratory reports (4, 7).

Two sets of conditions were employed. In one, the hydrolysis was continued until the concentration of the sugar being removed was 0.5 percent or less. In the other, the hydrolysis was continued until the average reducing-sugar content of the total hydrolyzate was approximately 5.0 percent. In the case of bark, the latter hydrolysis was discontinued when the concentration of the reducing sugar being removed was 1.0 percent or less, because at no time was the concentration of reducing sugar from bark as high as 5.0 percent. The values for the analysis, hydrolysis, and yields of alcohol from the various samples are given in table 1.

The yield of alcohol from bark was so low that the capacity of the hydrolyzer equipment to produce fermentable sugar was lessened. In order to increase this capacity, several tests were made in which either larger quantities of wood waste were charged into the digester by using higher packing pressures, or shavings or hogged bark-free slab wood were mixed with the hogged mill waste to reduce the average bark content of the total charge. In these tests, in which about 25 percent of the charge was bark, about 7 percent of the total alcohol obtained was from the bark. In order to have a uniform basis for comparison, however, the yields of reducing sugar and alcohol are expressed on the basis of bark-free wood. Table 2 gives the values for the wood waste containing varying amounts of bark and hydrolyzed by batch addition of the dilute acid and batch removal of the sugar solution.

Because of the greater ease of operation and control afforded by the method, several tests were made in which acid was continuously introduced and sugar solution continuously removed throughout the entire hydrolysis period. In most cases sugar solution began to flow from the bottom of the hydrolyzer about 15 minutes after the acid was first introduced. In many cases, the first sugar solutions to come off were only partially hydrolyzed. Values for the hydrolysis of wood obtained with the completely continuous process are given in table 3. Hydrolysis was discontinued when the average concentration of reducing sugar of the total hydrolyzate was approximately 5.0 percent.

In order to overcome the tendency toward only partial hydrolyzation of the first reducing sugar removed, the following changes in procedure were made: (1) 200 pounds of dilute acid -- 1.5 to 2 percent concentration -- was rapidly introduced; (2) 400 to 600 pounds, or the amount of acid of 0.5 to 0.6 percent concentration required to bring the ratio of dilute acid to wood to 3 to 1, was introduced at a rate of about 12 gallons per minute; (3) the reaction was allowed to continue for 30 minutes from the time the first acid was introduced, meanwhile maintaining the temperature at 150° C. by admitting steam at the bottom of the digester; (4) after this reaction period, the pumps were set to introduce 20 pounds of acid (0.5 to 0.6 percent solution) per minute and the temperature controller was set to increase the temperature 0.5° per minute until a temperature of 185° C. was reached, at which the run was continued until completed. The sugar solution was removed continuously through a flow controller at the same rate the acid was introduced. The hydrolysis was discontinued when the average reducing sugar concentration of the total hydrolyzate was about 5.0 percent. The solutions were neutralized under pressure with lime, cooled to 30° C., adjusted for pH to the final desired value, and then fermented. The procedure for fermentation is given in an accompanying report (8). The results of these hydrolysis tests and fermentations are given in table 4.

## Discussion

Assuming that the values in the last 22 runs of table 4 are representative of the charging capacity of the digester and of the mixture of wood waste available, an average charge of 319 pounds of dry, bark-free wood waste can be placed in a 27-cubic-foot digester. This corresponds to a charge of 11.8 pounds of dry, bark-free mixed wood waste per cubic foot. The average alcohol yield from the sugars produced by hydrolysis corresponded to 64.5 gallons per ten of dry, bark-free wood, or 0.38 gallon per cubic foot of digester space.

### Application of Findings to a Commercial Plant

Those values may be used in determining the capacity of the wood hydrolysis plant being constructed by the Defense Plant Corporation at Springfield, Oregon, formerly sponsored by the War Production Board and now by the Department of Agriculture.

The plant consists of 5 digesters, each with a capacity of about 2,000 cubic feet. Each digester will hold 11.8 tons of dry, bark-free wood, or 15.8 tons of the dry wood substance. In most cases moisture constituted about 40 percent of the total weight of the material charged into the digester and therefore the usual charge, including moisture, would be about 26.5 tons.

Loading equipment and valves are designed to charge and pack the digesters in about 30 minutes, and steaming and heating will require about another 30 minutes. Assuming the rate of flow of the initial charge of acid downward through the bed of chips to be a function of the depth of the bed, and the rate per foot traveled to be the same as in the 27-cubic-foot digester, 40 minutes will be required for the liquid to pass through the charge in the 2,000-cubic-foot digester instead of the 11 to 12 minutes required in the pilot-plant digester. The rate of hydrolysis of the cellulose is a function of acid concentration, time, and temperature (17) and is independent of the size of the digester. Since the introduction of the acid and removal of the sugar solution are continuous, no extra time need be allowed for the flow of hydrolyzing liquid through the charge after the run is started and until the pump is stopped, when another 40 minutes will be required to drain the liquid from the digester.

The over-all increase in time required because of the larger size of the commercial digester should therefore be only 55 to 60 minutes. The average time required for the last 22 runs listed in table 4 was about 2 hours and 50 minutes from the time the pumping started until the lignin was discharged from the digester. This would indicate that 4 hours should be sufficient for the same operation in the large digester and that, including the charging of the digester and heating, a 5-hour operating cycle would be possible. Such conditions would, of course, allow no time for repairs and possible need for removal of some lignin from a digester. It appears,



however, that the latter possibility has been removed because, in about 100 runs using continuous pumping with Douglas-fir mill waste, the equipment has never failed to blow the lignin completely from the digester. Even allowing an hour for such exigencies, or a 6-hour operating cycle, 20 charges of wood could be hydrolyzed per day. The yield of alcohol obtained in the last 22 runs of table 4 indicates that 760 gallons of alcohol could be produced from the sugars from one digester charge or 15,200 gallons per 24-hour day and 5,472,000 gallons per 360-day year for the whole plant. If a 5-1/2-hour cycle is possible, allowing 30 minutes down time per run, the output would be 16,550 gallons per day, or 5,950,000 gallons per year.

For the production of 15,200 gallons of alcohol per day, 236 tons of dry, bark-free wood, or 310 tons of dry wood with bark would be required. If the 5-1/2-hour operating schedule is used and 260 tons of dry, bark-free wood produce about 16,550 gallons of alcohol per day, 350 tons of dry wood substance with bark will be required.

Automatic control of the introduction of the acid and removal of the sugar solution, as well as automatic control of neutralization, makes better operation possible with less manpower. Improvements in a process for continuous fermentation which will be published in another report make possible savings in manpower and better distribution of the use of equipment for that portion of the operation also.

#### Cost of Production of Alcohol

There are many unknown factors in the cost of operation of such a wood-hydrolysis plant. Assuming the values for chemicals required and the yields of products obtained in the pilot plant as representative of what will be possible in a large plant, the cost of chemicals for processing 1 ton of dry, bark-free wood waste can be tabulated as follows:

Chemical	Amount required per ton of wood	Value of chemical per ton	Cost of chemical per ton of wood
	<u>Lb.</u>		
Acid	130	\$20.00	\$1.30
Lime	100	20.00	1.00
Nutrients )			
Caustic )	.....	.....	.20
Permanganate )			
			<u>\$2.50</u>

On the basis of a yield of 64.5 gallons per ton of wood the cost of chemical per gallon of alcohol produced would be 3.9 cents.

An average delivered price of \$2 per ton of dry, bark-free wood is assumed. Wood with bark and with moisture is to be used for the process, but since moisture and bark yield very little or no alcohol, the processor does not expect to pay for them. The presence of moisture and bark increases delivery costs and limits the distance wood waste may be transported. Two to 2-1/2 tons of material must be delivered at the plant for each ton of dry, bark-free wood. The cost for wood per gallon of alcohol produced on this basis is 3.1 cents.

The calculated labor requirement for the plant is 65 men. On the basis of present wage scales and other labor overhead, such as insurance, social security, and other expenses, the cost for labor would be 4 cents per gallon.

Other costs, such as electric power, water, maintenance, overhead, supervision, and extra wood waste that may be needed for the power plant are estimated to be 3.7 cents per gallon.

These values bring the cost of production, exclusive of plant amortization, to 14.7 cents per gallon. No credit is taken in these calculations for byproducts. Assuming that it is desirable to pay off as much of the cost of the plant as possible while alcohol prices remain high, and allowing 3 percent interest on the investment, the retirement of the principal in about 4 years for a plant producing 5,472,000 gallons per year would cost 13.7 cents per gallon. Amortization in 7 years with a production of 5,950,000 gallons would cost 7.6 cents per gallon, bringing the cost of production to between 22.3 and 28.4 cents per gallon, exclusive of any income from byproducts.

#### Byproducts of the Process

The daily byproducts of the process are about 100 tons of lignin (dry basis), 33 tons of calcium sulfate dihydrate, 6,000 pounds of furfural, 5,000 pounds of methanol, and about 11.8 tons of nonfermentable sugars dissolved in about 1,800 tons of water. Ready markets are available for the furfural and methanol, and income from these products can reduce the cost chargeable to the alcohol.

Until other markets are developed, it is expected that the lignin will be used as boiler fuel. On a dry basis, this lignin has a value of about 10,500 B.t.u. per pound. Normally the product will be obtained from the process with about 50.0 percent moisture. The sulfur content due to sulfuric acid will be about 0.16 percent. This value may be lowered by washing if a lower acid content is desired. It is believed that the lignin should supply most of the fuel required. This lignin is being tested as a resin extender, for plastics, as a carrier of chemicals for soils improvement, and as a source of new chemical products. If it is found that lignin should have a higher value in some of these or other fields than it has as fuel, it, too, may be used to reduce the cost of alcohol.

Calcium sulfate has value in some localities as a source of lime and sulfur for the soils. It is expected that its value for this purpose should care for its removal and transportation.

The 11.8 tons of nonfermentable sugars are largely xylose. Pilot-plant experiments on the growing of fodder yeast on these sugars are in progress and show some promise. This material may prove to be a very undesirable source of stream pollution if it is not used.

### Other Plants

There has been a great deal of interest in the possibility of producing alcohol from smaller quantities of wood waste, and for this reason the effect of plant size on production costs should be considered. The cost of the acid, lime, steam, wood waste, water, and power may differ in various parts of the country because of variations in distance from the point of production. In general, however, these variations will be small and will depend on the amount processed. That charge may be assumed to be fixed. The costs for labor and plant will differ, depending on the size of the plant. Labor required for a wood-hydrolysis plant depends on the number of operations to be performed rather than on the size of the equipment, and, therefore, is practically independent of size. In a plant producing one-fourth the amount of alcohol, the cost for labor would be approximately four times as much per gallon of alcohol produced.

It is possible that a plant built under peacetime conditions would cost less, and also that many of the simplifications found in the pilot-plant operations may result in a reduction in the cost of the equipment required but, in general, reduction in size does not result in a proportionate reduction in the cost of the equipment.

At present it is not possible to forecast the postwar price of alcohol. Assuming, however, that the cost of production is similar to that under prewar conditions, alcohol must be produced for 30 cents per gallon or less in order to compete with other sources. Under such conditions, a plant processing approximately 150 tons of wood waste daily would be about the smallest plant that could operate with a profit unless valuable uses could be found for the lignin.

### Conclusions

A pilot-plant process has been developed for converting wood waste, consisting of chipped slabs and edgings, sawdust, and shavings, into ethyl alcohol by allowing dilute sulfuric acid at temperatures from 150° to 185° C. to flow continuously through a bed of the wood waste until the cellulose is hydrolyzed, neutralizing the excess acid continuously under pressure with lime, and fermenting the neutralized sugar solutions.

The operating data from the pilot plant have been used to calculate the capacity and cost of operation of a commercial demonstration plant being constructed at Springfield, Oregon.

#### Acknowledgment

On behalf of the Forest Products Laboratory, the authors wish to express their appreciation to The Vulcan Copper and Supply Company, Cincinnati, Ohio, and The Bristol Company, Waterbury, Connecticut, for assistance in the installation and operation of the automatic control equipment.

Acknowledgment also is made to the following members of the Forest Products Laboratory staff: George J. Hajny, Martha L. Hannan, Sedgwick C. Rogers, and Ralph R. Marquardt for assistance in the fermentation experiments, and Janet L. Bubl, Mary N. Mitchell, and Albert A. Kline for the analytical determinations.

Valuable assistance was received from the Pacific Northwest Forest Experiment Station, Portland, Oregon, in obtaining representative samples of Douglas-fir mill waste.

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Table 1.--Composition and products from Douglas-fir sawmill waste

Form of wood	Composition		Yield of hydrolysis products					
			At 0.5 percent or less concentration of reducing sugar		At 5.0 percent concentration of reducing sugar		Alcohol	Alcohol
	Potential reducing sugar content	Potential fermentable sugar	Total reducing sugar	Fermentable reducing sugar	Total reducing sugar	Fermentable reducing sugar		
	Percent	Percent	Percent	Percent	Percent	Percent	Gallons per ton	Gallons per ton
Bark.....	37.5	26.4	18.4	11.2	15.3	9.3	16.9	13.9
Sawdust (13.5 percent bark).....	63.2	53.4	44.6	37.1	41.6	34.6	55.5	51.9
Slabs, bark-free.....	67.5	57.0	48.9	40.6	39.0	32.1	61.0	48.5
Slabs, mill-run (35 percent bark).....	56.3	47.4	38.7	31.0	30.4	24.4	45.0	36.6
Hog fuel & select removed (52 percent bark).....	50.9	42.1	35.3	28.3	29.2	23.4	42.5	35.1
Shavings <sup>2</sup> .....	67.6	57.1						

<sup>1</sup>Except in case of bark, where hydrolysis was discontinued when concentration of reducing sugar being removed is 1 percent or less.

<sup>2</sup>Pilot-plant hydrolysis not made because of inability to charge sufficient amounts in the digester.



Table 2.--Hydrolysis of Douglas-fir sawmill wood waste using batch addition of dilute acid and discontinuing the hydrolysis when the total hydrolyzate averages approximately 5.0 percent

Run No.	Kind of wood waste	Dry wood	Bark-free wood	Hydrolysis time	Sulfuric acid <sup>1</sup>	Reducing sugar solution	Solution concentration	Yield <sup>1</sup>	
								Reducing sugar	Alcohol
		Lb.	Lb.	Hours	Percent	Lb.	Percent	Percent	Gallons per ton
176	Hog waste.....	455	296	3.4	6.6	2,800	5.09	47.3	59.1
178	Do.....	500	324	3.3	6.9	3,200	4.75	47.0	58.8
179	Sawdust.....	430	370	3.0	6.3	3,250	4.97	43.8	54.9
194	Do.....	420	364	2.9	6.1	3,305	4.90	44.6	55.6
220	Do.....	350	302	2.9	7.6	2,950	4.82	47.0	58.7
221	Do.....	370	320	3.0	6.9	3,060	5.10	49.0	61.0
187	Hog waste, <sup>2</sup> / <sub>35</sub> percent; Shavings, 65 percent.....	354	300	3.0	7.0	3,250	4.53	45.2	56.5
188	Hog waste, <sup>2</sup> / <sub>54</sub> percent; Shavings, 46 percent.....	450	366	3.2	6.5	3,550	4.80	46.7	58.3
217	.....( <sup>2</sup> / <sub>3</sub> ).....	400	337	3.0	7.3	3,200	4.72	45.0	57.5
218	.....( <sup>2</sup> / <sub>3</sub> ).....	409	340	3.0	6.6	3,200	4.73	44.5	55.6
232	Lab-wood chips and sawdust.....	399	332	3.1	6.6	3,130	5.10	48.0	60.0

<sup>1</sup>Values based on bark-free wood.

<sup>2</sup>Hogged sawmill waste containing 50.9 percent bark.

<sup>3</sup>Hogged wood waste containing 40 percent shavings and 20 percent sawdust.

Table 3.--Continuous hydrolysis of a charge of Douglas-fir wood waste, using continuous addition of the dilute acid and continuous removal of the sugar solution

Run No.	Wood waste		Bark-free wood <sup>1</sup>	Time	Acid <sup>1</sup>	Solution	Reducing sugar concentration <sup>1</sup>	Reducing sugar yield	Alcohol <sup>1</sup>
	Hog fuel	Shavings							
	Lb.	Lb.	Lb.	Hours	Percent	Lb.	Percent	Percent	Gal./ton
263	282	108	294	2.6	6.5	2,400	4.95	40.5	50.5
264	292	102	294	2.6	6.8	2,400	4.67	38.2	47.6
265	300	123	321	2.5	7.5	2,700	4.56	38.3	47.9
266	320	151	362	3.0	5.5	2,800	4.55	36.5	45.7
267	282	170	364	2.7	5.0	2,880	5.10	40.3	50.3
269	310	148	363	3.0	6.5	3,250	4.87	43.7	54.6
273	255	144	315	2.5	5.7	2,600	5.08	41.9	4
274	231	141	293	2.7	7.4	2,300	5.20	40.6	50.9
275	235	146	301	2.3	5.2	2,530	5.30	44.6	55.7
276	246	151	316	2.7	5.3	2,830	5.03	45.0	58.2
278	230	142	294	2.7	6.6	2,800	4.83	46.0	57.5
284	235	143	296	2.8	5.9	2,800	4.36	41.1	51.5
285	280	147	329	3.0	4.6	2,800	4.77	40.5	50.8
286	283	109	293	2.8	6.1	2,440	4.88	40.6	50.8
287	290	131	319	3.0	5.7	2,800	4.96	43.7	54.6
288	282	120	303	2.7	5.8	2,400	5.00	39.7	49.6
289	294	104	295	2.7	5.8	2,400	4.30	35.0	43.8
292	500	.....	326	2.8	5.5	2,800	5.00	42.9	54.6
293	278	151	331	3.0	8.0	2,800	5.04	42.6	53.3
294	273	165	344	3.0	6.0	2,800	5.00	40.7	51.0
295	298	137	330	2.8	5.7	2,800	4.86	41.2	51.6
296	290	140	329	3.0	6.2	2,800	4.75	40.5	50.6

<sup>1</sup>Values calculated on the basis of bark-free wood.

Table 4.--Hydrolysis of Douglas-fir sawmill wood waste, using batch addition of first charge, followed by continuous introduction of acid and continuous removal of sugar solution

Run No.	Hog fuel B (35 percent bark)	Shavings	Dry wood	Bark-free wood	Hydrolysis time	Acid	Reducing sugar weight	Reducing sugar concentration	Yield, bark-free wood	Alcohol concentration	Yield
	Percent	Percent	Lb.	Lb.	Hours	Percent	Lb.	Percent	Percent	Gm. per 100 ml.	Gal. per ton
243	100	.....	451	294	3.0	5.8	3,020	5.05	52.0	1.96	65.0
245	100	.....	465	302	3.0	6.2	3,000	5.08	50.3	1.97	63.0
246	75	25	448	328	3.1	5.4	3,100	5.18	48.8	2.03	61.0
249	75	25	470	340	3.0	4.5	2,900	5.25	45.0	2.04	56.0
250	72	28	478	344	2.7	4.9	2,700	5.65	45.6	2.20	57.0
252	50	50	460	370	3.0	5.0	2,980	5.15	41.5	2.01	52.0
253	50	50	436	357	2.8	5.4	3,100	4.90	42.3	1.90	52.0
254	52	48	434	354	3.1	5.6	3,200	5.48	48.0	2.12	60.0
255	54	46	447	364	3.1	5.6	3,300	5.18	47.0	2.14	60.2
256	54	46	447	364	3.1	5.6	3,300	5.18	47.0	2.01	58.9
257	100	.....	444	290	2.9	7.0	3,200	4.85	53.3	1.89	65.6
262	70	30	385	293	2.8	6.7	3,000	5.01	51.5	1.95	64.3
268	62	38	457	358	3.2	6.3	3,640	4.96	50.5	1.94	63.2
270	56	44	380	314	2.6	6.5	3,100	4.95	49.0	1.93	61.3
271	59	41	383	313	2.7	6.5	3,000	5.06	48.5	1.97	60.7
277	65	35	380	296	2.7	6.7	3,100	4.92	51.5	1.92	64.3
279	70	30	417	319	2.9	7.0	3,500	5.00	54.8	1.95	68.5
280	65	35	412	322	2.8	6.5	3,500	5.00	54.5	1.95	68.0
281	64	36	405	318	2.8	6.8	3,500	4.80	52.7	1.87	66.0
282	67	33	392	302	2.8	6.8	3,200	4.85	51.4	1.89	64.2
283	67	33	386	299	2.8	6.8	3,200	5.10	54.5	1.99	68.2
290	67	33	415	319	2.8	7.0	3,200	5.00	50.2	1.95	68.7
291	72	28	450	339	2.5	5.5	3,200	5.30	50.2	2.06	62.7
297	68	32	405	308	2.7	7.0	3,120	5.04	50.8	1.96	63.7
298	49	51	387	303	2.9	7.2	3,300	5.10	55.5	1.99	69.0
299	67	33	449	343	2.7	6.4	3,650	4.80	50.8	1.87	67.5
302	70	30	391	285	2.6	7.3	3,200	4.85	54.5	1.89	68.2
303	71	29	407	305	2.8	6.8	3,315	4.90	53.1	1.91	68.5
304	70	30	401	301	2.6	6.8	3,100	5.10	52.5	1.98	65.5

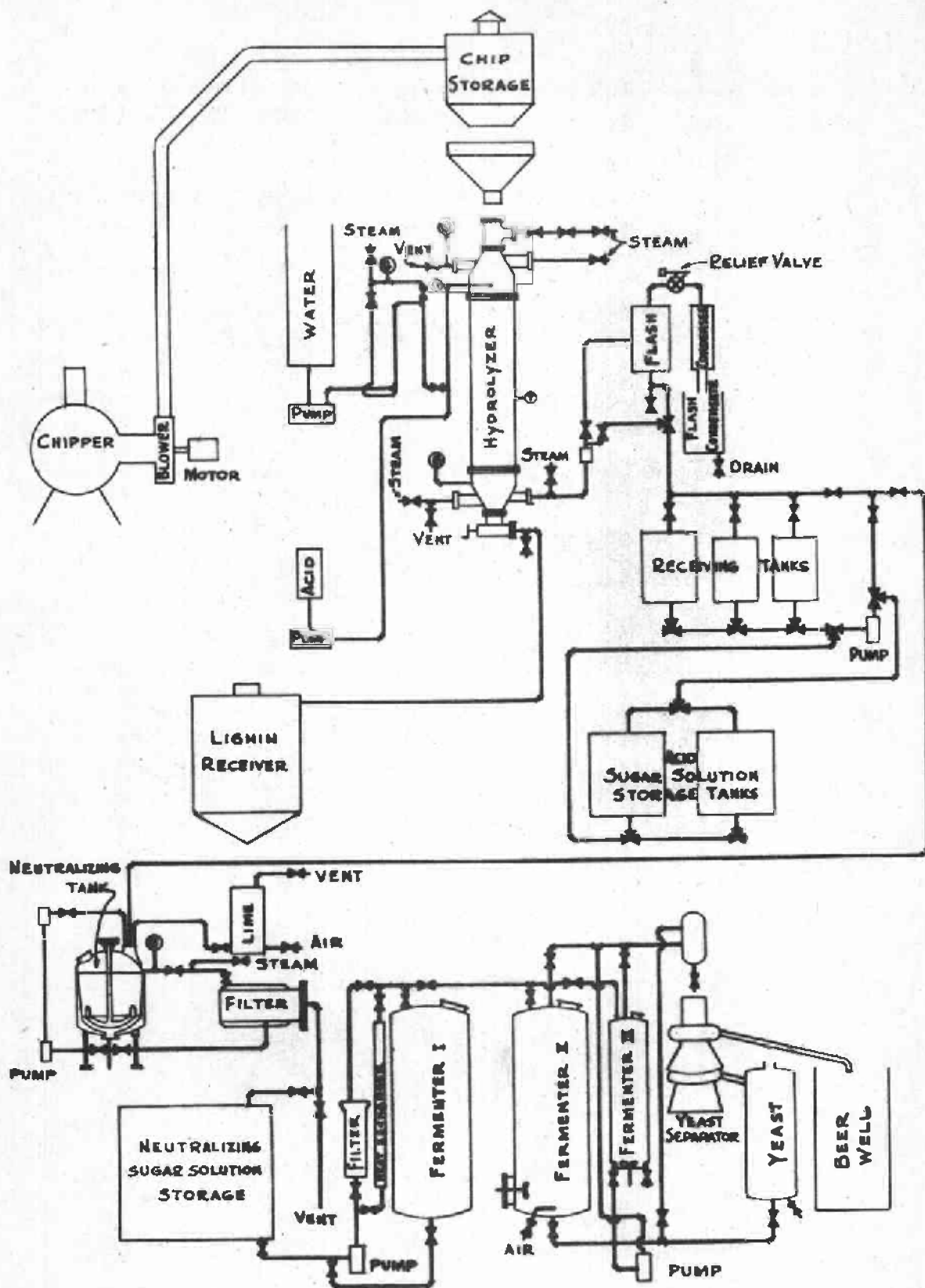


Figure 1.--Equipment for saccharification of wood and fermentation of wood sugar solutions.

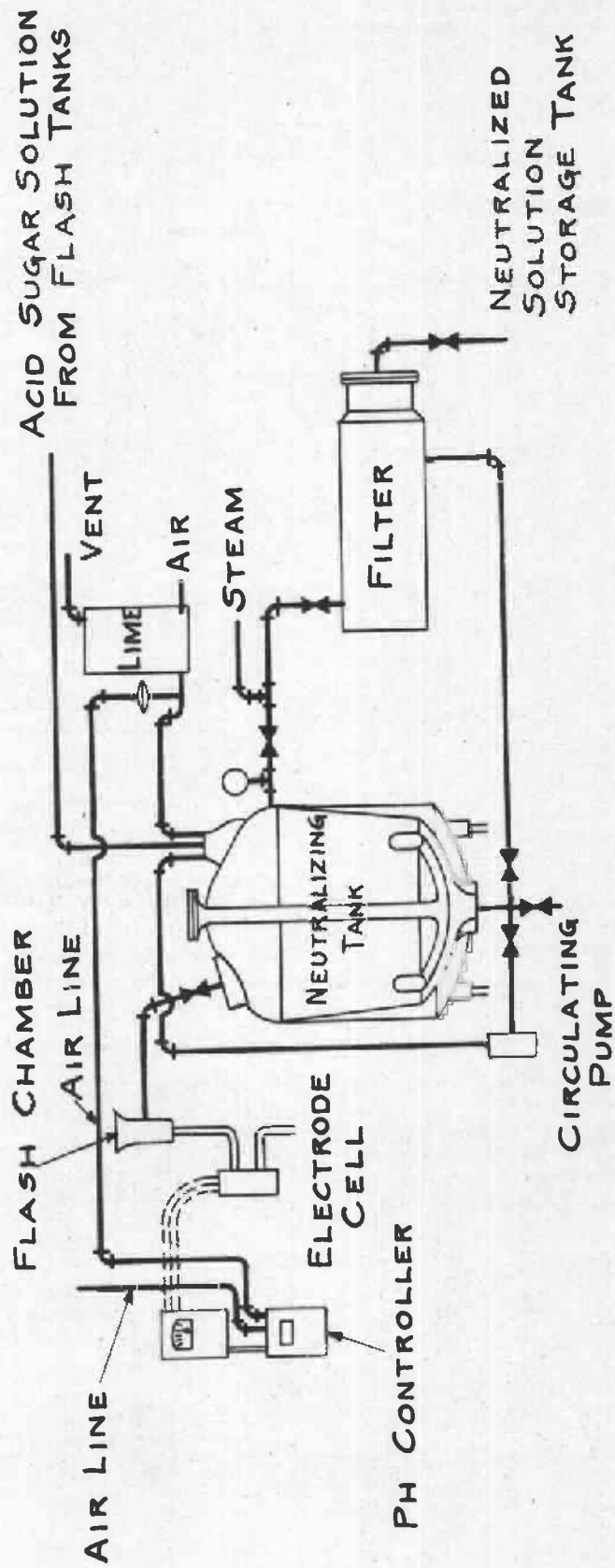


Figure 2.--Equipment for neutralization of wood sugars.