# The Feasibility of Commercial Utilization

## Of

# Cotton Fabric and Conversion Products

## For

# SYNTHETIC LUMBER


By

**FREDERICK W.** illiam **zur BURG** III



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## PREFACE

This paper is an abstract of the dissertation presented in partial fulfillment of the requirements for the degree of Doctor of Philosophy by Frederick W. zur Burg, in the Department of Chemical Engineering at the Virginia Polytechnic Institute, Blacksburg, Va.

The original dissertation is on file in the Library at the Virginia Polytechnic Institute and is available for study and review.

*Committee on*
*Graduate Programs and Degrees*

# Cotton Stalks *for* Synthetic Lumber*

**F. W. zur BURG**

▸▸▸ DURING THE PAST TWO DECADES much scientific investigation has been directed toward the elimination and profitable utilization of the waste products of manufacture and agriculture. One of the outstanding developments has been an industry that utilizes agricultural waste products to produce synthetic lumber. Such materials as cornstalks (*1*), bagasse (*2*), wheat straw (*3*), wood (*4*), whole cotton plants (*5*) and etc., have entered into the manufacture of the different synthetic lumbers, and the different products have met with varied degrees of success.

An investigation was undertaken to determine the feasibility of utilizing cotton stalk as a basic material in the manufacture of synthetic lumber. The cotton stalk is not just an ordinary waste, but a highly undesirable refuse when left standing in the fields; for, during the winter months the dead plant acts as a home for the boll weevil then in its dormant stage.

The cotton stalk used in this investigation was gathered immediately after the cotton had been picked. This stalk was not freed from dirt or foreign plant matter since it was desired to utilize a raw material in the investigation which would approximate as nearly as possible the raw material that a manufacturing plant could expect to buy if it were buying cotton stalk. The stalks were allowed to air-dry for six months before being used. At the end of this period, the moisture content of the stalks was determined and found to be approximately twenty per cent on the moist basis.

Prior to forming a pulp, it was necessary to reduce the cotton stalk to a state resembling chips. For this operation, a hammer mill was found to produce a satisfactory material. The hammer mill used in this work was equipped with quarter-inch openings in the screens. The product of the hammer mill contained five different components: (1) wood-like chips; (2) bast fibers; (3) flakes of bark; (4) fragments of other plants; and (5) dirt.

A first attempt was made to produce a pulp by cooking these chips with caustic soda in a manner similar to the production of soda pulp. For this purpose, a small digester, similar in construction to the commercial units, was made from 8-inch steel pipe. The bottom was forged conically and equipped with a blow-off valve. The top was fitted with a blind flange and this flange could be removed for the purpose of charging the digester. The digester was equipped with ¾-inch steam lines and a steam gauge.

In a series of runs, weighed amounts of chips, caustic soda and water were charged to the digester. The different cooks were made under differing steam pressures, varying amounts of caustic and for varying periods of time. The amount of bone-dry fiber resulting from each cook was determined by discharging the cooked product from the bottom of the digester, washing the black liquor from the discharged product, drying and weigh-

***Table I—The effect of time, caustic concentration and steam pressure on the yield of fibers resulting from the cooking of cotton stalk chips.***

| Run No. | Bone-dry weight of stalk (Grams) | Weight of NaOH used (Grams) | Time of cook (Hours) | Steam Pressure Lb/sq. in. (Gauge) | Bone-dry yield (Grams) | Yield (per cent) |
|---|---|---|---|---|---|---|
| A* | 404 | 60.6 | 0.5 | 90 | 234 | 57.9 |
| B* | 323 | 48.5 | 0.75 | 90 | 180 | 55.7 |
| C* | 323 | 48.5 | 1.0 | 90 | 163 | 50.5 |
| D* | 323 | 48.5 | 1.25 | 90 | 175 | 54.2 |
| E | 404 | 60.6 | 2.0 | 90 | 200 | 49.5 |
| F | 323 | 48.5 | 3.0 | 90 | 149 | 46.1 |
| G* | 321 | 80.0 | 0.5 | 90 | 196 | 61.1 |
| H* | 321 | 80.0 | 1.0 | 90 | 168 | 52.3 |
| I | 321 | 80.0 | 1.5 | 90 | 147 | 45.7 |
| J | 321 | 80.0 | 2.0 | 90 | 155 | 48.3 |
| K | 321 | 80.0 | 3.0 | 90 | 141 | 43.9 |
| L* | 321 | 80.0 | 0.5 | 40 | 240 | 74.8 |
| M* | 321 | 80.0 | 1.0 | 40 | 199 | 62.0 |
| N* | 321 | 80.0 | 2.0 | 40 | 188 | 58.6 |
| O | 321 | 80.0 | 3.0 | 40 | 173 | 53.8 |

(*) The product of these runs contained wood-like particles which were insufficiently digested and these particles would not yield to the action of a laboratory beater.

(*) Abstract of a thesis submitted to the Department of Chemical Engineering of the Virginia Polytechnic Institute, Blacksburg, Va., in partial fulfillment of the requirements for the degree of Doctor of Philosophy.
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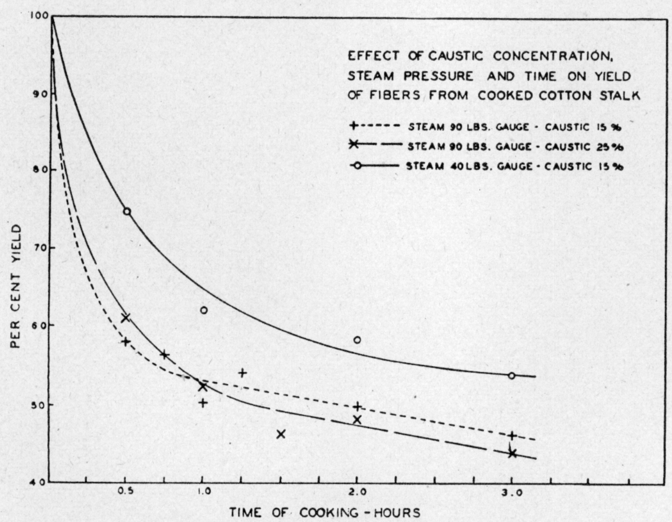

FIGURE 1

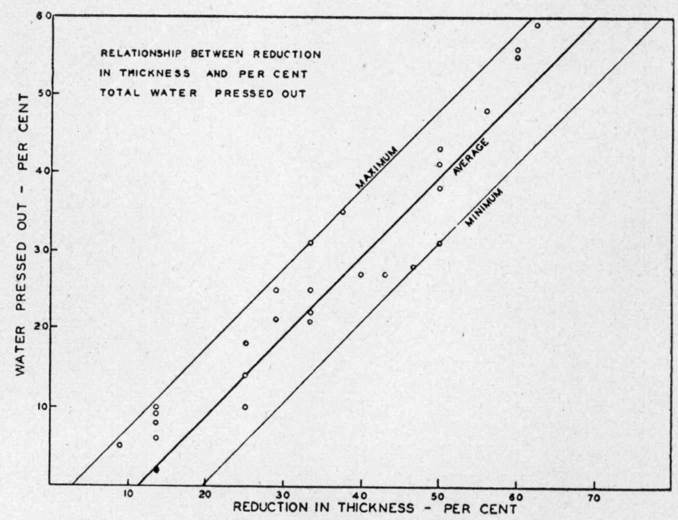

FIGURE 2

ing the dried fibers. The results of this series of cooking operations are given in Table I, and the data of this table are platted in Figure 1. It will be noticed that the points do not fit the uniform curve. This discrepancy is partially attributed to the fact that it was very difficult to obtain uniform samples, that is, samples which contained the same amount of the five components produced by the hammer mill. It is apparent that the increase in steam pressure has a greater effect on the digestion than the concentration of caustic from 15 to 25 per cent.

As indicated by the data in Table I, the best yield that can be expected when chips formed by the hammer mill are treated by the methods indicated will approximate 50 per cent. A pulp formed by this process also entails the problem of caustic recovery on the black liquor. With these two facts in mind, it was decided to attempt another method of forming a pulp from cotton stalks.

In certain studies (*1*) it has been shown that pulps could be formed from corn stalks by grinding the stalk in a rod mill. It has also been shown (*6*) that when cellulosic materials are mechanically worked in the presence of water, the cellulose undergoes a hydrolysis that results in the formation of a number of degradation products and that if the hydrolysis is stopped at the proper point, a mucilaginous substance is formed. This mucilaginous material might serve as a binder between the fibers.

With the above facts in mind, attempts were made to form pulps from the cotton stalk chips which were produced by the hammer mill. The rod mill used for this purpose was a Patterson eighteen-inch pebble mill. The total weight of the steel rods used amounted to 53.25 pounds and these rods varied in diameter between 1.25 inches and 0.5 inch.

In the first instance, an attempt was made to form a pulp by grinding one pound of chips with amounts of water varying between ten and fifteen pounds. Under these conditions the bast fibers were completely reduced within the first five to ten minutes of grinding and the wood-like particles were subjected to very little grinding action since they floated on the surface of the water and escaped the action of the rods. When the water chips ratio was reduced below six or seven pounds of water per pound of chips, the mass tended to pack and line the interior of the mill, and again little grinding action resulted. Therefore the ratio of one pound of air dried chips to six or seven pounds of water was used in subsequent experimentation.

***Table II—Variation of Freeness with Time of Grinding.***

| Time (Minutes) | Freeness (Seconds) | Comments |
|---|---|---|
| 0 | ...... | |
| 5 | ...... | |
| 10 | ..... | Woody portions float. |
| 15 | 100 | No visible change in stalk. Brown color. |
| 20 | 240 | Few particles float. Much darker in color. |
| 25 | 600 | Well pulped. Black in color. |
| 30 | 900 | Little change in appearance. |

**(Note: In this grind, one pound of stalk was used with six pounds of water)**

A freeness tester as described by Sweeney (*1*) was used to check on the progress of the pulping action of the mill. The results are tabulated in Table II.

Considering Table II, it appears that for a grinding time of fifteen minutes or less, the rods have not had sufficient opportunity to reduce the wood-like chips to a fibrous condition and with a grinding time of twenty-five minutes or more the freeness is too high to give a satisfactory pulp. At the end of approximately twenty minutes grinding, a definite change may be seen in the product. The color of the charge changes from brown to black and the mass becomes rather gelatinous. At this point and under these conditions, it is apparent that the gelatinous hydration product of cellulose commences to form in appreciable quantity.

The stocks used to form the mats in the following series of experiments were made by grinding one pound of air dried chips with six or seven pounds of water for a period of twenty-five minutes. In each instance, the pulps from the rod mill were made up to 5 per cent consistency running this stock onto a stationary wire. The wet mats were pressed or rolled free of excessive moisture before being subjected to further treatment. The mat, formed by this method, was dried in a Proctor and Schwartz dryer. At the completion of the drying period, the mat possessed little strength since the fibers were not sufficiently in contact with each other. Atmospheric drying was highly unsatisfactory since the mat fermented and deteriorated beyond the point of usefulness.

The best method of drying consisted in heating and pressing small mats measuring 5 in. by 5 in. between the hot platens of a hydraulic press.

In studying the relationship between the decrease in thickness of the mats and the amount of water pressed out (as shown graphically in Figure 2), a linear relationship was obtained.

Figure 3 shows the relationship between the reduction in thickness and the pressure required to attain this reduction. As indicated in Figure 3, the amount of pressure required increases very rapidly with uniform increments of decreasing thickness.

While in the hot press, the surfaces of the mats were covered with 16-mesh screen in order to allow moisture to escape more freely from the surface

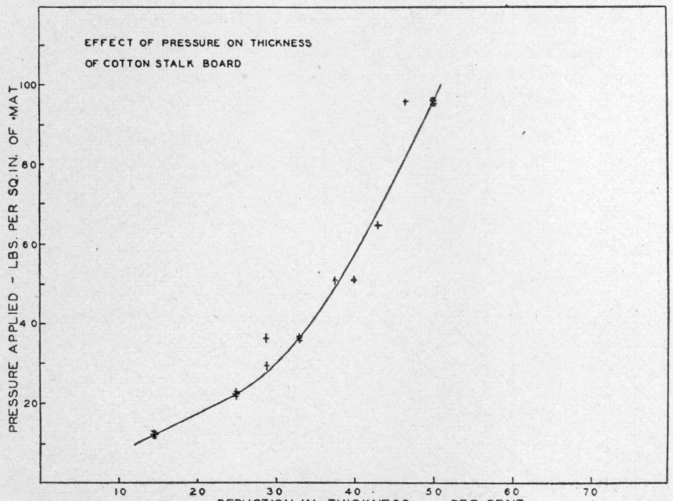


FIGURE 3

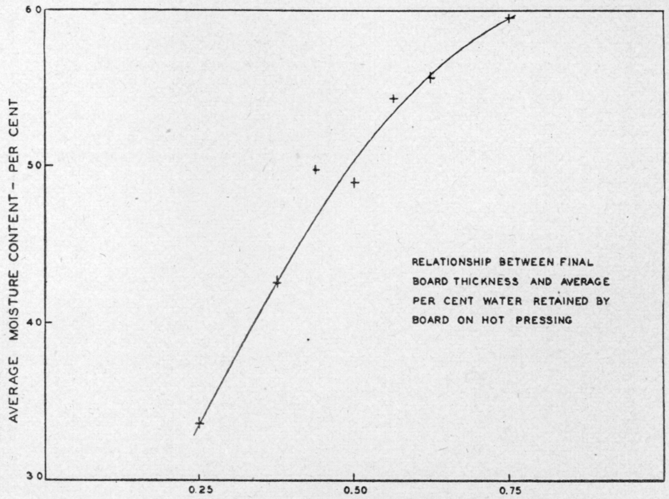


FIGURE 4

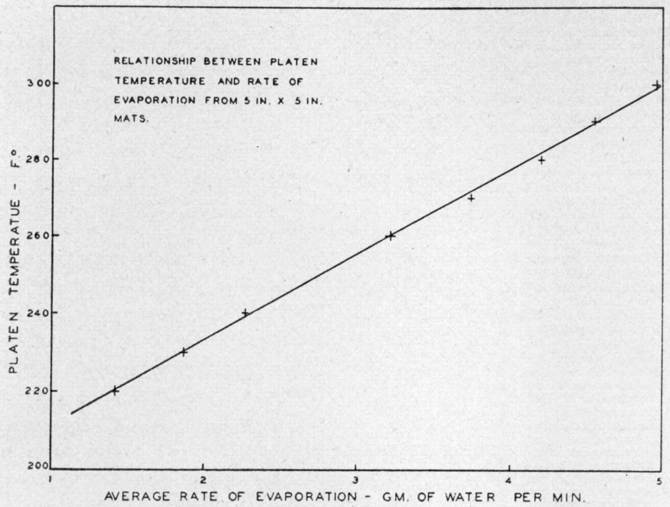


FIGURE 5

*Table III*

| | |
|---|---|
| 1. Raw material costs: | |
| Cotton-stalk | $ 81,690.00 |
| Raw water | 2,160.00 |
| Steam | 12,150.00 |
| Power | 35,352.00 |
| Total raw material costs | $131,352.00 |
| 2. Building and Equipment Costs: | |
| Manufacturing space | $ 13,020.00 |
| Storage space | 57,232.00 |
| Land | 2,000.00 |
| Rail siding | 5,000.00 |
| Truck | 1,200.00 |
| Magnetic separator | 1,000.00 |
| Hammer mill | 1,650.00 |
| 2 Rod mills | 36,000.00 |
| Forming machine and rolls | 17,500.00 |
| 2 Hydraulic presses | 190,000.00 |
| Drying house and racks | 161,000.00 |
| Saws | 4,470.00 |
| Skid platforms | 2,300.00 |
| Boiler and equipment | 13,590.00 |
| Miscellaneous equipment | 17,586.00 |
| Total for building and equipment | $532,548.00 |
| 3. Labor and Supervision: | |
| As listed above | $ 57,200.00 |
| 4. Fixed Charges: | |
| Taxes | $ 13,089.00 |
| Insurance | 2,618.00 |
| Social security | 1,038.00 |
| Depreciation | 26,177.00 |
| Total fixed charges | $ 42,922.00 |
| 5. Working capital: | |
| Raw material costs | $131,352.00 |
| Labor and supervision | 57,200.00 |
| Fixed charges | 42,922.00 |
| Incidentals | 2,500.00 |
| Total working capital | $233,974.00 |
| 6. Capital Investment: | |
| Building and equipment | $523,548.00 |
| Working capital | 233,974.00 |
| Total capital investment | $757,522.00 |
| 7. Annual operating cost: | |
| Raw materials | $131,352.00 |
| Labor and supervision | 57,200.00 |
| Fixed charges | 42,922.00 |
| Maintenance at 5 per cent | 26,177.00 |
| Total operating cost | $257,651.00 |
| Annual production (30,000,000 sq. ft. at $15/1000) | $450,000.00 |
| Possible return (annual) | $192,000.00 |

of the mats. During the heating and drying of the mats, the press was opened at five minute intervals and the surfaces of the mats were examined. The mats were removed from the press when the surfaces had completely dried. This was determined by the ease with which the wire screen could be separated from the surface of the mat.

The thicker mats retained a relatively greater quantity of water than the thinner mats on hot pressing. A curve showing the relationship between the final pressed thickness of the mats as removed from the press and the average moisture content retained is given in Figure 4.

The rate of evaporation of water from the mats was a function of the platen temperature. A curve showing the rate of evaporation of water versus platen temperature is shown in Figure 5.

After the surfaces of the mats had been dried in the hot press, the mats still contained a high per cent of moisture. The mats were removed from the hot press, placed on a shelf covered with wire gauze and allowed to dry in the atmosphere. These mats were turned periodically to prevent warping. The moisture in the mats reached an equilibrium with the moisture of the air in about two weeks time. At the end of this time the final moisture content of the mats amounted to about 15 per cent of the weight of the mats on the wet basis.

The weight losses occurring on the board forming machine in the mechanical pulping process are relatively low when compared with the soda process. Drain water contained 0.440 per cent total solids divided between 0.126 per cent mineral solids and 0.314 per cent organic matter. The mineral content of washed stalk was determined as 6.6 per cent; considerable dirt contained on the surface of the original stalks is removed in the board forming operation. Eighteen pounds of water have been removed from each pound of pulped chips up to the air drying operation. Some of this water was lost on the forming machine and some in the press. For each pound of chips fed to the rod mill then the total loss amounts to 8 per cent or 0.079 pounds. There is also a weight loss of about 2 per cent in the hammer mill, but this is principally inorganic matter.

Tests on the product of the mechanical process indicate that the boards have a modulus of rupture which varies between 80 and 500 lb. per sq. in. On the average, the thinner boards showed a greater strength than the thicker boards. The thermal conductivity of the product varied between 0.291 and 0.708 B.t.u./hr./F.°/sq. ft./in.

## Commercial Feasibility of the Process

In making a study of the feasibility of manufacturing a synthetic lumber

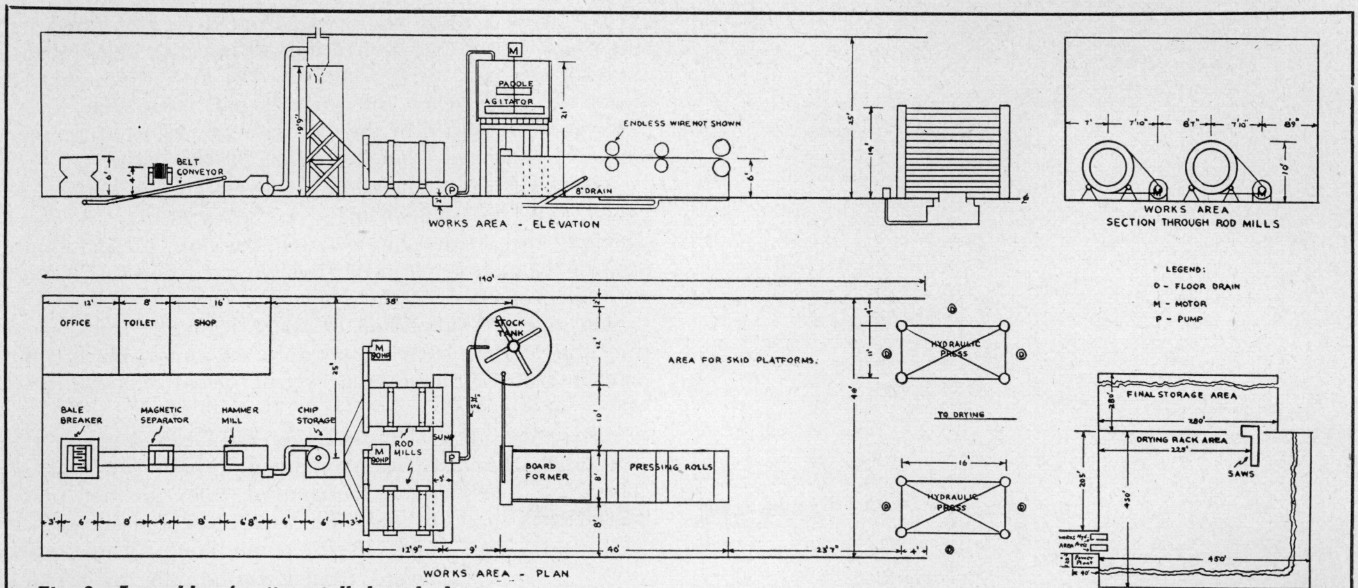


***Fig. 6—Assembly of cotton stalk board plant.***

from cotton stalk by the mechanical process, the methods indicated by Vilbrandt (7) were used. It was calculated that the total cost of mowing, baling, and bringing one ton of cotton stalk to the plant would approximate $5.85. Regardless of the fact that the farmer does himself a service by removing the stalk from his land in that he lowers the boll weevil hazard, it was decided to figure the cost of the stalk to the plant at $7.00 per ton in order to encourage the steady supply of stalk. The design calculations were based on an annual output of thirty million square feet of half-inch board per year.

In Figure 6, the plan and elevation of the proposed plant is given. It will be noted that the bales of cotton stalk enter the plant at the bale breaker. This machine has a capacity of 2,400 bales per day. The broken bales then pass to a hammer mill of the Gruendler "Wood-Hog" type, where the chips are formed through quarter-inch screens. Following this the chips are passed to two 6 ft. x 12 ft. rod mills for pulping. The stock from the rod mills is made up to a 5 per cent consistency and sent to a board forming machine of the "Ames" type. On this machine, water is removed both by suction and by pressing between rolls.

The wet mats from the forming machine are then sent to one of two hydraulic presses. The plates of these presses should be steam heated and should measure 100 in. x 200 in. Each press has twenty openings. On leaving the presses, the pressed board is allowed to air dry in racks for a period of two weeks and then sent to a set of saws. These saws are located between the drying house and the final storage house.

The manufacturing section of the building presented in this design is of brick construction while the drying house and the final storage section is of corrugated iron construction.

It was calculated that the following labor and supervision would be necessary to operate the plant: One general manager at $5,000 per annum; three technical men at $2,400 per annum; one clerk at $1,800 per annum; 44 common laborers at $3.00 per diem and two truck drivers at $6.00 per diem.

A preconstruction cost accounting on a 300 day/year basis was made on the process with the results shown in Table III.

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2) Lathrop, E. C., *Indus. and Eng. Chem.*, 22 449-60 (1930)

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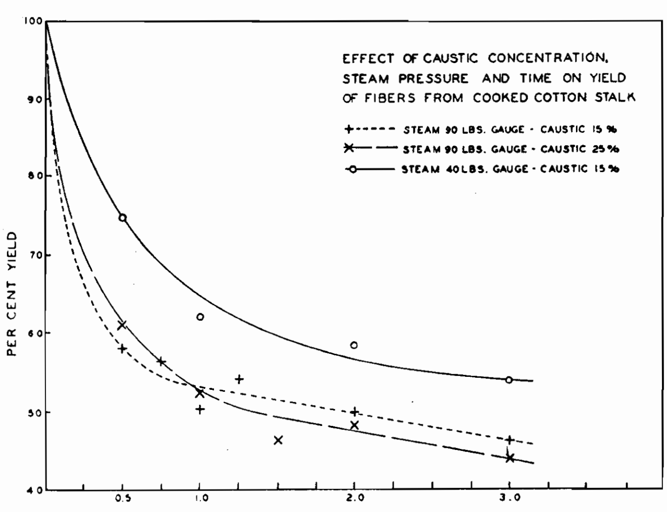

FIGURE 1

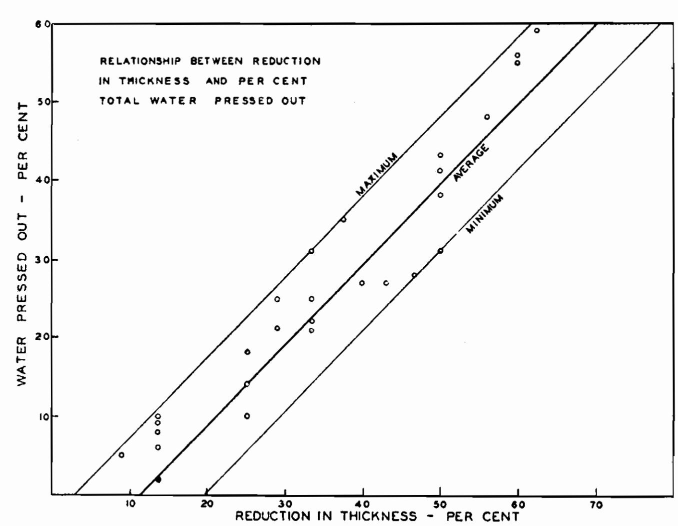

FIGURE 2

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***Table II—Variation of Freeness with Time of Grinding.***

| Time (Minutes) | Freeness (Seconds) | Comments |
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Considering Table II, it appears that for a grinding time of fifteen minutes or less, the rods have not had sufficient opportunity to reduce the wood-like chips to a fibrous condition and with a grinding time of twenty-five minutes or more the freeness is too high to give a satisfactory pulp. At the end of approximately twenty minutes grinding, a definite change may be seen in the product. The color of the charge changes from brown to black and the mass becomes rather gelatinous. At this point and under these conditions, it is apparent that the gelatinous hydration product of cellulose commences to form in appreciable quantity.

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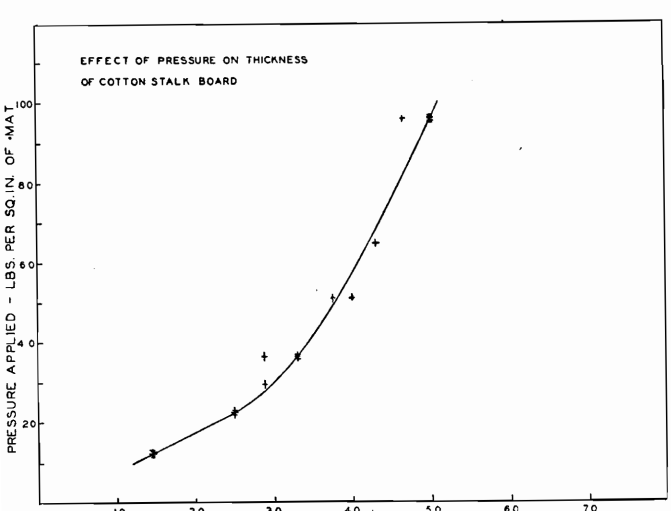


FIGURE 3

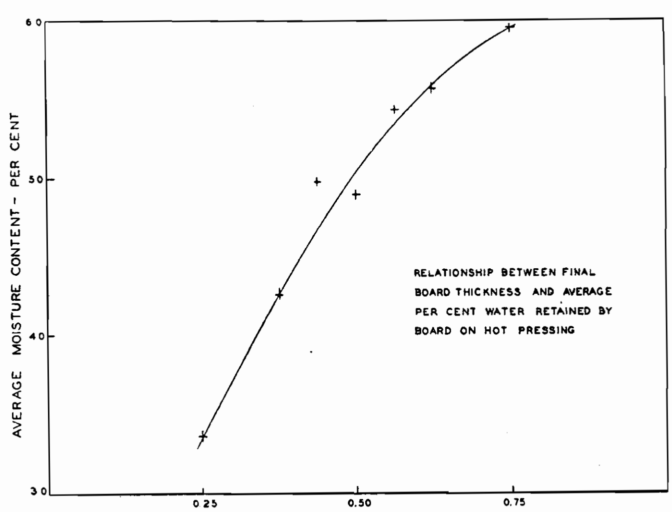


FIGURE 4

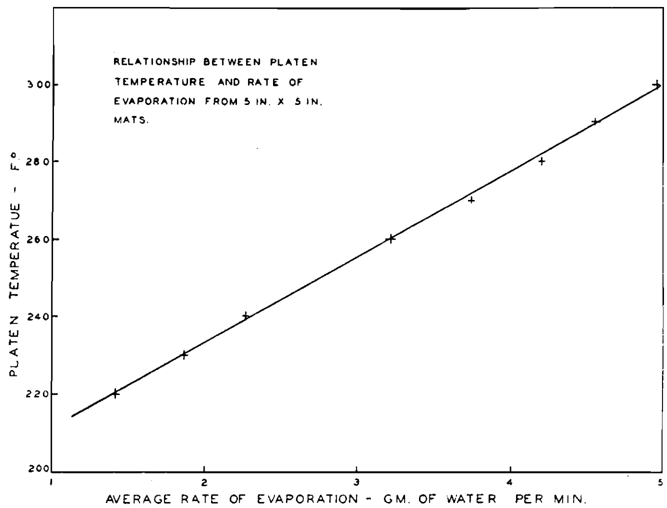


FIGURE 5

***Table III***

| | |
|---|---|
| 1. Raw material costs: | |
| Cotton-stalk | $ 81,690.00 |
| Raw water | 2,160.00 |
| Steam | 12,150.00 |
| Power | 35,352.00 |
| Total raw material costs | $131,352.00 |
| 2. Building and Equipment Costs: | |
| Manufacturing space | $ 13,020.00 |
| Storage space | 57,232.00 |
| Land | 2,000.00 |
| Rail siding | 5,000.00 |
| Truck | 1,200.00 |
| Magnetic separator | 1,000.00 |
| Hammer mill | 1,650.00 |
| 2 Rod mills | 36,000.00 |
| Forming machine and rolls | 17,500.00 |
| 2 Hydraulic presses | 190,000.00 |
| Drying house and racks | 161,000.00 |
| Saws | 4,470.00 |
| Skid platforms | 2,300.00 |
| Boiler and equipment | 13,590.00 |
| Miscellaneous equipment | 17,586.00 |
| Total for building and equipment | $532,548.00 |
| 3. Labor and Supervision: | |
| As listed above | $ 57,200.00 |
| 4. Fixed Charges: | |
| Taxes | $ 13,089.00 |
| Insurance | 2,618.00 |
| Social security | 1,038.00 |
| Depreciation | 26,177.00 |
| Total fixed charges | $ 42,922.00 |
| 5. Working capital: | |
| Raw material costs | $131,352.00 |
| Labor and supervision | 57,200.00 |
| Fixed charges | 42,922.00 |
| Incidentals | 2,500.00 |
| Total working capital | $233,974.00 |
| 6. Capital Investment: | |
| Building and equipment | $523,548.00 |
| Working capital | 233,974.00 |
| Total capital investment | $757,522.00 |
| 7. Annual operating cost: | |
| Raw materials | $131,352.00 |
| Labor and supervision | 57,200.00 |
| Fixed charges | 42,922.00 |
| Maintenance at 5 per cent | 26,177.00 |
| Total operating cost | $257,651.00 |
| Annual production (30,000,000 sq. ft. at $15/1000) | $450,000.00 |
| Possible return (annual) | $192,000.00 |

of the mats. During the heating and drying of the mats, the press was opened at five minute intervals and the surfaces of the mats were examined. The mats were removed from the press when the surfaces had completely dried. This was determined by the ease with which the wire screen could be separated from the surface of the mat.

The thicker mats retained a relatively greater quantity of water than the thinner mats on hot pressing. A curve showing the relationship between the final pressed thickness of the mats as removed from the press and the average moisture content retained is given in Figure 4.

The rate of evaporation of water from the mats was a function of the platen temperature. A curve showing the rate of evaporation of water versus platen temperature is shown in Figure 5.

After the surfaces of the mats had been dried in the hot press, the mats still contained a high per cent of moisture. The mats were removed from the hot press, placed on a shelf covered with wire gauze and allowed to dry in the atmosphere. These mats were turned periodically to prevent warping. The moisture in the mats reached an equilibrium with the moisture of the air in about two weeks time. At the end of this time the final moisture content of the mats amounted to about 15 per cent of the weight of the mats on the wet basis.

The weight losses occurring on the board forming machine in the mechanical pulping process are relatively low when compared with the soda process. Drain water contained 0.440 per cent total solids divided between 0.126 per cent mineral solids and 0.314 per cent organic matter. The mineral content of washed stalk was determined as 6.6 per cent; considerable dirt contained on the surface of the original stalks is removed in the board forming operation. Eighteen pounds of water have been removed from each pound of pulped chips up to the air drying operation. Some of this water was lost on the forming machine and some in the press. For each pound of chips fed to the rod mill then the total loss amounts to 8 per cent or 0.079 pounds. There is also a weight loss of about 2 per cent in the hammer mill, but this is principally inorganic matter.

Tests on the product of the mechanical process indicate that the boards have a modulus of rupture which varies between 80 and 500 lb. per sq. in. On the average, the thinner boards showed a greater strength than the thicker boards. The thermal conductivity of the product varied between 0.291 and 0.708 B.t.u./hr./F.°/sq. ft./in.

## Commercial Feasibility of the Process

In making a study of the feasibility of manufacturing a synthetic lumber

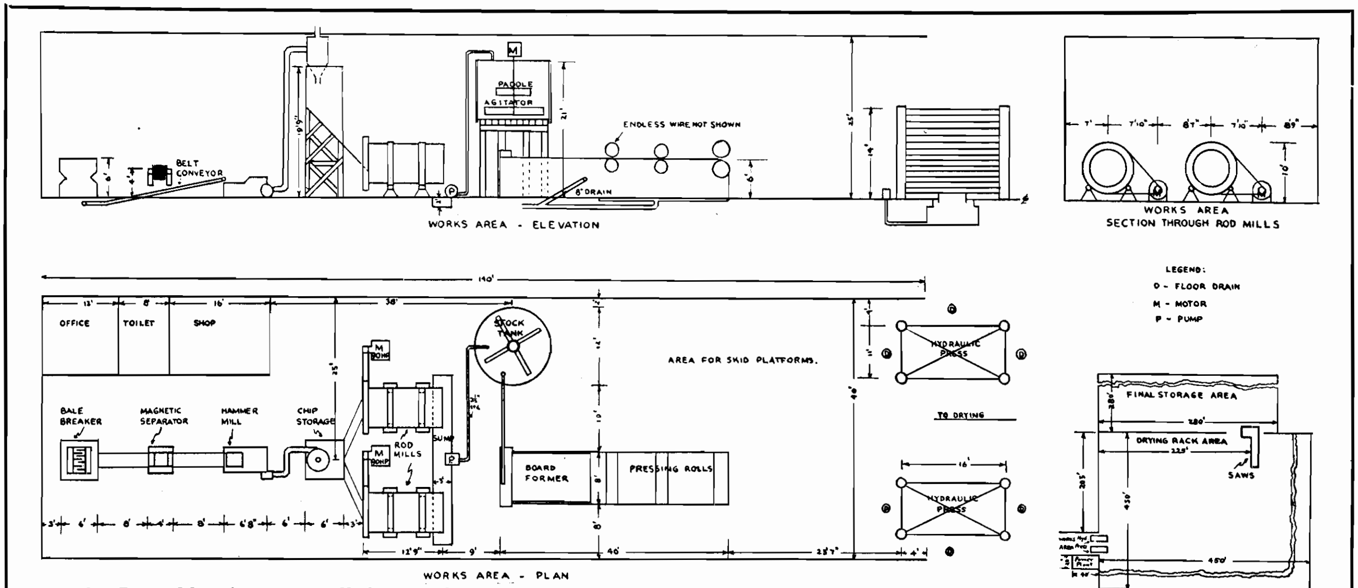


*Fig. 6—Assembly of cotton stalk board plant.*

from cotton stalk by the mechanical process, the methods indicated by Vilbrandt (7) were used. It was calculated that the total cost of mowing, baling, and bringing one ton of cotton stalk to the plant would approximate $5.85. Regardless of the fact that the farmer does himself a service by removing the stalk from his land in that he lowers the boll weevil hazard, it was decided to figure the cost of the stalk to the plant at $7.00 per ton in order to encourage the steady supply of stalk. The design calculations were based on an annual output of thirty million square feet of half-inch board per year.

In Figure 6, the plan and elevation of the proposed plant is given. It will be noted that the bales of cotton stalk enter the plant at the bale breaker. This machine has a capacity of 2,400 bales per day. The broken bales then pass to a hammer mill of the Gruendler "Wood-Hog" type, where the chips are formed through quarter-inch screens. Following this the chips are passed to two 6 ft. x 12 ft. rod mills for pulping. The stock from the rod mills is made up to a 5 per cent consistency and sent to a board forming machine of the "Ames" type. On this machine, water is removed both by suction and by pressing between rolls.

The wet mats from the forming machine are then sent to one of two hydraulic presses. The plates of these presses should be steam heated and should measure 100 in. x 200 in. Each press has twenty openings. On leaving the presses, the pressed board is allowed to air dry in racks for a period of two weeks and then sent to a set of saws. These saws are located between the drying house and the final storage house.

The manufacturing section of the building presented in this design is of brick construction while the drying house and the final storage section is of corrugated iron construction.

It was calculated that the following labor and supervision would be necessary to operate the plant: One general manager at $5,000 per annum; three technical men at $2,400 per annum; one clerk at $1,800 per annum; 44 common laborers at $3.00 per diem and two truck drivers at $6.00 per diem.

A preconstruction cost accounting on a 300 day/year basis was made on the process with the results shown in Table III.

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