THE DESIGN OF A CONTAINER BOARD MILL

By

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1929 ---- 1930
Subject: THE DESIGN OF A CONTAINER BOARD MILL.

Foreword

A problem which often confronts the mechanical engineer of today is the design of an industrial plant, which might be a factory, mill or producing plant for one or thousands of products.

This paper will treat on one such problem, specifically, the design of a Container Board Mill. The treatment will be largely explanatory; i.e., detailed explanation and description of various steps in design, together with the necessary calculations for same, will be offered for clearness of understanding to anyone who might read the paper. Further, every design problem has its specific set of controlling data from which every phase of the problem is attacked in the proper order after an engineering fashion, the calculation and results properly arranged and sufficient explanation offered for each step in the procedure. Also, good and sufficient reasons should be offered for recommendations of special machinery, equipment or systems. The specification of any except standard and labor-saving equipment should be avoided. A set of data, a site for the mill and other conditions governing the design of a board mill will be assumed for this problem, and will be outlined in detail in a later paragraph.

Container Board.

Description: A brief description, or we might say, analysis of container board will be offered at this point for the benefit of those who are not familiar with different kinds of paper and its uses. Container board might be defined as "Heavy paper composed of several plies or thicknesses of thin paper combined into a single sheet, or preferably, board, by the use of excessive pressure". The exact method will be explained in detail in another paragraph.

The accepted standard recommended by the Container Board Association of America is a board of sixteen one-thousandths (0.016) inches in thickness, eighty-five (85) pounds Mullen test and weighing seventy (70) pounds per one thousand (1000) square feet. The mullen tester is a machine, also accepted by the Container Board Association of America, for use in determining the tensile strength of paper. The test referred to above, 85 pounds, is the force in pounds per square inch required to punch a hole through a sheet of standard container board. A diagram of the Mullen tester is shown in figure one of blue-print number one. The sheet, (13) is clamped tightly between plates (11) and (7) by turning the handwheel (12) so that the screw (12) attached to it is threaded into the frame (1) at the point (a). Number (8) is a rubber diaphragm about 1/8" in thickness. It is held in place by (7) and (6) as shown in figure number 2. The area of hole in (7) through which the diaphragm protrudes when pressure is applied to the glycerine in the well by number (4), is one square inch. The sheet is clamped in place then the hand wheel number (2) is turned to the right so that the screw (5) is threaded into the frame (1). This forces the
A Sheet of Container Board .016 in. thickness

Pressure Gage 5-350 pounds.

Fig. 1. Diagram of the Standard Mullen paper tester.

"Knocked down Carton. Seared and Slotted and ready to be folded and taped as shown in Fig. 3 (b).

Fig. 3 (a).

Assembled carton. End C is fastened to end E by means of a strip of cloth tape about 2" wide as shown in above sketch.

Fig. 3 (b).

Cut from a sample of standard Corrugated or (combined) board. The corrugated sheet, no 2 is standard .009 "straw board.

Fig. 4 (a).

Sample of fibreboard composed of 3 sheets of .016 "container board glued together.

Fig. 4 (b).
piston (4) against the glycerine in the well (3), which in turn transmits the pressure to the gage (9), and at the same time against the rubber diaphragm at (8). The force with which the diaphragm at (8) presses against the sheet of paper (13) is registered on the gage in pounds per square inch, since the area in the plate (7) and also of the rubber pressing against the sheet at this point is one square inch. Pressure is brought to bear on the sheet by means of the hand wheel (2) until the rubber "pops" through the sheet as stated before, the gage reading the force required to pop through a standard .016 caliper sheet should show a reading of 85 pounds per square inch. A sample sheet of standard container board is included in this report between pages 2 and 3. A mullen test is also shown on this sample sheet to give an idea of how the paper fails under an even pressure such as is obtained in the testing machine.

Process of Manufacture: Although this problem deals with the standard or 85 pound test board, the process of manufacture is largely the same for all board ranging in test from 25 pounds to 300 pounds. The only difference being in the waterproofing, finish, color, sizing and etc., which is really supplementary to the standard process. The same equipment can be used for manufacturing all types and thicknesses or calipers of container board.

The name, Container Board, nearly defines or we might say, explains its use, which is in the manufacture of containers or boxes for shipping purposes. This is a vast industry and the paper box is steadily supplanting the use of wood in the manufacture of shipping containers. There are two distinct types of paper board containers, namely, solid fibre and corrugated containers. Figures three and four of plate number one illustrate a container or carton, "knockeddown" and assembled, and samples of the boards of which the container, as illustrated, may be composed. The carton as illustrated in figure 3 (b) is ready to be filled with goods and sealed. The top, as shown in the open position in the illustration is sealed in the same manner as the bottom, as shown in the figure by first folding in the end flaps, (5) and (7) and then the side flaps, (6) and (8), onto the end flaps. The tape is then applied as shown, covering the seam between flaps (6) and (8).

Figure 4 (a) shows a piece cut from a combined corrugated board. (1) and (3) are sheets of container board and (2) is a corrugated sheet of strawboard, which is straw paper of about nine one-thousandths (.009) inches in thickness. The sheets of container board are glued to the tips of the corrugations of the straw board at points (4) as shown, with adhesive Silicate of Soda, thus making a rigid piece of paper board from three sheets of heavy, but pliable paper.

Figure 4 (b) illustrates a piece of solid fibre board, composed of 3 (or more ) layers of container board glued together with adhesive Silicate of Soda. Fibre Board varies in thickness from 1/16" to 1/8".

The above explanation and description together with the illustrations of container board and some of its uses are offered as a means of conveying to the reader some idea of the nature of the product, the design of a producing mill for which this paper will cover.

Print number two is a diagramatic sketch of a standard container board mill. This sketch illustrates in a simple manner,
A SAMPLE OF .016" CALIPER CONTAINER BOARD

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the entire process machinery and treatments through which the raw materials (see appendix I) must pass in the process of being formed into a continuous sheet and thence into a finished roll of container board. The processes, machines, treatments and handling of materials will be explained and described in detail as follows. (References will be made to plate number two and sketches shown thereon.)

Beginning at the left hand side of the sheet (plate number two) we have shown the raw stock room. Numbers (1) and (2) are the raw materials, waste papers and kraft, which, together with the chemicals from chemical laboratory (72) are treated and subsequently formed into a sheet or container board in the following manner:

The proper proportions of waste paper (1) and kraft (2) are hoisted by means of a crane (3), which functions on the rails (71), and deposited into the beating engine (4). At the same time, the proper amount of water from the supply tank (47) is furnished to the beater through the pipe (48), and the chemicals from the chemical laboratory (72). The power for turning the beater roll (6) is supplied by the motor (5). The motor pulley is belted to the beater roll pulley (80). The beating engine derives its name from its action upon the furnish (waste papers and kraft sheets). References is here made to blue print number 4(a) which shows a sketch of a beater (cross section, figure (1) and plan, figure 2).

Beaters used in container board mills are of the "Holland" type, i.e., the stock and water circulate in a large iron or concrete tub (concrete is almost obsolete). Figure (2) on plate (4) shows a plan view of the tub (4), roll (6), spindle (93), mid-feather or dividing rib (94), pulley (80) on spindle and the arrows show the direction of circulation of the stock and water mixture in the tub. The tub is generally made of cast iron cast in sections for bolting together when set in place in a mill. The size of the tub varies with the requirements, the average being such that it will accommodate a ton (2000 pounds) of dry stock (papers and kraft sheets) and enough water to make a ratio of 94% water and 6% stock by weight. This is calculated in the following manner.

Let X equal the weight of water in the beater.

Then if the beater is furnished with 2000 pounds (one ton) of stock,

\[
2000 = 0.06 \times X \\
X = \frac{2000}{0.06} = 33,333 \text{ pounds of water in the beater.}
\]

Since there are 8 1/3 pounds of water per gallon, then

\[
33,333 \times 8 \frac{1}{3} = 4,000 \text{ gallons of water furnished to a one ton beater.}
\]

The average tub for a one ton beater is about four feet deep by nine feet wide by twenty-two feet in length and weighs several tons. The cast iron of the tub is about 3/8" in thickness. The bottom of the tub is of concrete poured after the tub has been set-up, bolted together and leveled. The bottom of the tub slopes toward the roll since the flow of water and stock is desired to be in this direction, to facilitate the beating action between the beater blades (81) and the bed plate bars (83), figure 1. The beating action, or better, the amount of beating is regulated by a device known as a "Lighter Beam" (96)
Fig. 1. Cross Section thru Beater Tub Showing Roll and Bed Plate.

Fig. 2. Plan of Beater.
Fig. 3
DETAIL OF BEATER ROLL, SPINDLE, BEARINGS AND PULLEY.

Fig. 1.
DETAIL OF LIGHTER BEAM (96) AND STAND (99), SHOWING ADJUSTING DEVICE FOR BEATER ROLL (4).

Fig. 4.
DETAIL OF BEARING END OF LIGHTER BEAM.

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Fall, 1929 - 30.                  Print No. (4-6)
and stands (99) as shown in figure (1) blue print number 4(b). The roll (6) is raised away from or lowered toward the bed plate (82) by turning the hand wheel (98) to the right or to the left. The hand wheel is attached to the threaded screw (97). The top of the stands (99) are threaded for the screws the lower ends of which bear on the top of the heavy spring (100) as shown, which in turn bears on the top of the end of the beam. The ends of the beam, in turn, rest on the lighter springs (101) which compress more easily than those above (100), thus allowing the adjustment to be made up or down without compressing the upper spring. The upper spring is inserted in the lighter stand as a safety device and functions in the following manner: When a large "Wad" of paper passes between the roll and the bed plate, as sometimes happens, the upper or safety spring (100) compresses and allows the roll to rise in the bearings (102), and the wad to pass through. If it were not for this safety device the journals of the roll would be broken. All of this equipment is very heavy since the roll is large, 48 to 70 inches in diameter and approximately four feet long, and weighs, together with the large spindle which is 8 or 10 inches in diameter and the pulley keyed to it, several tons. A sketch of the roll, spindle and pulley is shown in figure 3, print number 4(b). The roll frame or skeleton is composed of two cast iron heads (105) and one cast iron spider (103). The blades or knives (81) are set into the slots in the heads and bear on, or are supported by, the spider (103). They are all fastened in these slots by a specially designed key ring (118) shrunk fitted in place and are wedged apart and braced by the wooden wedges (104) as shown in figure 5. The wedges are made of white oak.

The large pieces of furnish (87) together with the smaller pieces (84) which are already partly beaten, are drawn between the iron bed plate (82) which contains the projecting cutting bars (83) and the beating roll (6) which contains the projecting knives (81), by the centrifugal action on the roll (6) in the furnish (84, 86 and 85). The excessive "suction" between the bed plate and the roll is due to the high peripheral speed of the roll which varies between 1800 and 5000 feet per minute. The result is a beating or shredding action on the pieces (87) so that after the process has continued for the required length of time the large pieces of furnish are all beaten into a pulp and mixed with water so as to resemble a thick mush full of fibres. The actual average composition of the finished or beaten furnish is about six per cent stock and ninety-four per cent water, by weight, as explained in a preceding paragraph.

The beater stock or furnish is then dumped into the beater chest directly below the beater through the discharge pipe (87). Due to the fact that the beaten furnish plus water is rather thick and tends to pack or settle to the bottom of the chest, an "agitator" (8) which is a shaft provided with paddles as shown, is installed in the chest and rotated at a slow speed by motor (9) through a reducing gear to stir the beaten furnish, which from now on we shall call "stuff" (trade name among paper makers). The chest is generally made of reinforced concrete with walls about 4 - 6 inches in thickness, and with a capacity of about 3 or 4 beaters, or twelve to sixteen thousands of gallons of stuff (6% paper fibres and 94% water.) Pump number (10) draws the stuff from the beater chest through the suction pipe (17) and discharges it through the discharge pipe (11) to the Jordan engine (12) which is driven (direct) by the motor (13).
Jordaning is a name given to the process of finish grinding or refining the stuff, that is, grinding and tearing apart the paper fibres and also cutting and shortening so that they will form a smoother and stronger sheet. Referring to blue print number 5 -- figure (2) is a section through a Jordan engine. The stuff from the beater chest enters the Jordan through the intake pipe (92). The core (90) of the engine is provided with a filling of blades or knives (89) which project about an inch from the body of the core. This core is made of cast iron and is slotted for the blades which are set into the slots and locked in place by a special locking device. The blades are about 5/16 inches thick. The Jordan is set or adjusted for fine or coarse cutting by means of the hand wheel (105) and the screw (107). By turning the hand wheel to the right the core (90) is forced into the shell, and since the core and the inside of the shell are conical, this forces the blades on the core and the projections (88) on the inside of the shell closer together, and hence, produces finer cutting. The Jordan engine is about four feet high and twelve or fourteen feet long and weighs several tons. Jordans are rated in tons per hour, that is, the number of tons of stock which they will refine per hour, one, two, three, etc. The shell (12) is cast with projections (88) as shown in figure 1. Stuff travels through the Jordan from the low or small end to the high or large end in the same manner that a belt travels on a cone pulley. Since the core rotates at considerable speed and the knives are set very close to the projections on the inside of the shell, a very decided cutting action is obtained and the result is a much finer stuff or stock with shorter fibres and more of them. Since a sheet of paper, or paper board, is composed of thousands of small fibres like short pieces of thread, interlocked or interwoven and pressed together, the softness or hardness and the strength of the sheet varies with the amount of pressure and the length and the strength of the component fibres. The beating and the Jordan engines disassemble these fibres in the old or waste papers and also in the kraft or wood pulp sheets and prepare them for the new sheet of paper or paper board. The pressing action or process of forming these fibres into a solid sheet is obtained in a paper machine as will be explained later.

From the Jordan engine the stuff flows through pipe (49) to the Jordan or machine chest (14). The stuff in this chest is agitated by the agitator (15) driven by motor (16). Pump number (19) draws the stuff through the suction pipe (18) and forces it through pipe (20) to screen (21) which is driven by motor (22). The action of the screen in a paper mill might be compared to that of the sieve or sand screen used by the mortar mixer. The mortar mixer shovels sand onto a screen or sieve and shakes it. The fine pebbles of a certain size pass through the meshes of the screen and the larger ones remain on the other side, or in short, are separated from the fine ones which are to be used in the mortar. The same thing takes place in a paper mill screen. A shaker screen is a brass plate about 2 feet by 6 feet (flat) provided with small slots about .003 inches wide and 3/8 to 1/2 inches long. These plates are agitated or shaken by a shaft provided with cams which work against springs attached to the carriage supporting the plates and the boxes in which they are fastened with bolts.
Sectional Elevation of a Jordan Refining Engine.

Fig. 1
End View
(Section thru Core and shell).

Fig. 2
Floor line

Not drawn to scale.
When the stuff is pumped onto the screens the fine fibres of the proper size and length to form a good sheet of paper pass through to the container or box below and those fibres which are too large to pass through the screen are scraped off the screens and returned to the beater chest to be refined or re-jordaned. The stuff which passes through the screens flows through pipe (23) to the machine head box (24) and thence thru feeder pipe (25) to the cylinder vat (26) of the paper machine. The head box (24) is a "Feeder" box for the cylinder vats, i.e., the amount of stuff flowing to the vats is regulated by valves or gates in this box so that only the required amount to form a sheet of paper or board reaches the vats. If it were not for this means of regulating the supply of stuff at the vats they would overflow and cause a waste. Blue print number 6 shows a detail sketch of cylinder vat for a paper machine. It might be well to add here that there are two distinct types of paper machines, namely, the Fourdrinier and the Cylinder machines. The Fourdrinier is used for making paper of .009 inches and less in thickness and will not be described in this paper. The Cylinder machine in its simplest form, is shown diagramatically on blue print number 2.

Referring to blue print number (6), which shows a plan and a cross section of a cylinder vat, the size of the vat varies with the capacity and width of the machine. If the machine requires a cylinder (27) 3 feed in diameter by 6 feet in length, then the overall dimensions of the vat would need to be about 3 1/2 feet deep by 6 feet wide by 8 feet long. The improved type of vat has cast iron ends and 3 inch cypress sides, ends and partition boards (112).

The cylinder itself is formed of 6 cast iron spiders with hubs, spokes and flat rims as shown in the cross section. The inside of the cylinder is hollow as shown. The frame is completed by passing brass rods about 3/8 to 1/2 inches in diameter through holes in the rims of the four middle spiders and riveting the ends of these rods into the two end spiders. These rods are then wrapped, spirally, with a heavy copper wire (about 3/32 inches); the spirals being spaced so as to leave an opening between them of about 1/8 inches. This frame work is then covered with a very fine mesh copper screen and the face of the cylinder is ready for the deckel straps (111), which are rubber bands wrapped around each end, as shown in figure 2, to regulate the width of the sheet of paper formed on the cylinder. The ends of the cylinder fit very closely against the ends of the vat as at "A" and "B" so as to be as nearly water tight as possible. The cylinder and vat unit functions as follows: Stuff enters the vat through pipe (25) at "D" and travels as indicated by the small arrows, upward over the first baffle board (112) down between boards (112), thence under the left hand board and upward toward the face of the cylinder. Now the pump (110) draws the water with which the stuff is mixed through the face of the cylinder to the interior of the cylinder and thence as indicated by the arrows (114) through the suction box (115) and suction pipe (116), and discharges it through pipe (117) to screens. This suction inside the cylinder draws the fibres against the face of the cylinder and there
Fig. 2
PLAN

Fig. 1
CROSS SECTION THROUGH CYLINDER AND VAT.

Fig. 3
DETAIL OF CYLINDER

Discharge back to screens

Motor

Pump

Coupling

Screen covered face or cylinder

B

C

110 suction (116)

114

115

26

111 A

Couch Roll (28)

Bottom felt (29)

Clear H₂O

Paper fibres

Felt Roll

Stock from Hd Box No 24

108 109

26

113

109
they remain until the "felt" (29) picks them up as indicated figure 1, plate (6). The couch roll (28) is heavy and rides on the felt and cylinder, pressing the felt against the face of the cylinder causing said felt to rotate the cylinder in the vat, the felt, in this case acting as a belt driving a pulley. The couch roll also presses part of the water from the paper fibres which the felt (29) removes from the face of the cylinder by means of the nap or felt fibres which compose the surface of a paper makers felt. In this manner a soft sheet of fibres or paper is formed on the under surface of the felt next to the cylinder.

From this point the felt (29) carries the sheet thus formed around the suction roll (31) which removes additional water from the sheet and the felt, thence around and between the first pair of felt rolls (50) at which point the bottom felt (29) meets the top felt (30). From this point on until it reaches the first big press the sheet is carried between the top and bottom felts and the process of felting or arranging the fibres in the sheet of board being formed is carried on.

Felts for cylinder machines vary in width, depending upon the width of paper required. If the sheet is to trim to a finished width of 65 inches, then the felt should be about 70 inches wide. The length of the felt (top and bottom felts are endless, i.e., like a driving belt running over pulleys) depends upon the number of cylinders, press rolls, and hence, upon the length of the "Wet end" of the paper machine in general. In the sketch shown there are two "baby" presses (32) and (34) and two big presses (35) and (36). All parts of a paper machine are numbered both ways from the 1st. press (35). A text could easily be written on the importance of the felt in paper making, and it might be well to add that the discovery of the fact that the "nap" on a piece of woolen cloth or felt (purest of wool" would pick the fibres of paper off of a cylinder of the type described in a preceding paragraph, made possible the use of the cylinder or wet machine for making the heavier types of papers and eliminated the slow hand process by which these papers were formerly made. The felt also has many other qualities which make it indispensable to the paper maker—such as, action in shedding water from the sheet, imperviousness to the acid salt, alum, strength and wearing qualities and others too numerous to mention.

Figure 1, plate number 6 shows a clear water shower (113). The purpose of this shower is to wash from the face of the cylinder the paper fibres and foreign substances which remain there after the felt has removed its share of the fibres. The shower consists of a two inch pipe with a row of 1/8 inch holes about 3/4 inches apart for a length equal to the width of the face of the cylinder and on the side next to the cylinder. The overflow from the vats, the water pressed from the sheet between the press rolls, that beaten from the felt by the whipper roll (40), together with any other water used about the wet end collects in the pit (41) and is pumped by pump (42) through pipe (44) by motor (43) to the saveall (45) in which the stock is separated from it, and thence through pipe (46) to the beater supply tank (47).
Returning to the paper process, the sheet being formed emerges from the first press (35) on the top side of the bottom felt (29) and is carried thus to the second big press (36) where it is removed by the doctor blade (37). From the "pinch" of the second press the bottom felt is carried downward around a felt roll, thence to the whipper (40), (there is also a shower at the whipper which helps to clean the bottom felt, and if the machine is equipped with a felt conditioner, this device is also installed between the second big press and the whipper) and on to the cylinder to pick up another layer of fibres -- thus making a continuous process and a continuous sheet of paper. The sheet of paper (58) containing probably 60% moisture by weight emerges from the pinch of the second press, is carried across to the first dryer (51), over the roller (50) and threaded around the dryers as shown, thence around the "dandy" roll (54) to the calendar stack (55) through the calendar rolls driven by the motor (56), to the reel (59) and wound into a roll (62). Figure (62) is a roll of paper or container board being unwound, passed through pull rolls, cut to the desired width by slitters (65), pulled the slitters by pull rolls (63) and rewound by the winder (67) into finished rolls (66), ready to be removed from the winder shafts and stacked into the finished paper warehouse by means of the hoist and traveling crane (69) and (70). The rewinder is driven by the motor (68).

The raised or open part of the building indicated directly over the dryers is called the ventilator and is built for the purpose of allowing the steam which rises off the sheet as it passes over the dryers, to escape upward and out to the atmosphere -- hence facilitating the speeding up of the drying process, which is a very important item, especially if the speed of paper travel is a requirement as it is in a good many of the larger mills today.

The Power Plant. The power plant, which is so necessary to the operation of a paper mill, is one of the most important factors in the design. The sketch on plate number two does not show a power plant; but it will be described, in brief, as follows:

The small modern paper mill power plant generally includes a large boiler or battery of small boilers, a feed water pump, a water softener, a superheater (built into the boiler) fuel feeding equipment for the boiler, feed water heater, steam engine direct connected to a generator or steam turbo-generator for the generation of current to be used for driving motors throughout the mill, and a control panel for distribution of the current to these motors.

A paper mill requires a large amount of power for driving the process machinery which handles heavy loads, therefore most of the motors or driving engines are large. The cost of power for a mill, therefore, becomes a large item. In the north country water power is abundant and therefore cheap and whenever possible the mill is located so as to take advantage of this form of power. The waterwheel is direct-connected to a generator which generates the current necessary to drive the motors. The
raw materials used, labor, market and transportation facili-
ties, however, are important items which must also be consi-
dered in the problem of choosing a site for a container board
or paper mill, and these items sometimes affect the choice of
sources of power for the mill.

If steam engines are used there are two kinds or types
best adapted to paper mills:— the constant speed and the
variable speed types. The constant speed engines are used to
drive all pumps, agitators and whippers. The variable speed
engines are used to run the paper machines so that the caliper
and speed may be varied, depending upon the amount of paper
which can be dried. The Corliss engine is the most economical
in a paper mill since it will carry from seven to fifteen
pounds of back pressure and this is the amount of exhaust steam
generally carried in the dryers. If turbo-generators are used
in the power plant, then the turbine should be of the bleeder
type so that steam may be drawn off at the required pressure
for use in the dryers and also for heating purposes (radiators)
throughout the mill. The General Electric and the Terry Turbine
units are very popular today among paper mill builders.

Water. A paper or container board mill is generally built on a
small stream, river, or inland lake, which will furnish a con-
stant supply of good clear water. Salt water is not desirable
since it cannot be used in boilers raw on account of the foam
and scale produced. Water may also be pumped from specially
provided wells, but this is so expensive as to be prohibitive,
as a paper mill uses such large quantities for showers, washing
felts and screens, wires, and mixing paper stock. For example,
four thousand gallons of water are mixed with two thousand
pounds or one ton of stock in each beater-full of furnish. If
fifty tons of stock is furnished to the beaters in twenty-four
hours, then the beaters alone will use fifty times four thou-
sand or two hundred thousand gallons of water per day.

The water used in a paper mill should be soft (as possible)
since lime, iron and other like impurities are injurious to felts,
boilers, etc. Generally a centrifugal or a plunger pump is used
for pumping the water from the source of supply to the point of
use in the mill. That which is to be used in the beaters is
pumped into a large supply tank and heated with steam coils
(covered by the water in the tank) to a temperature of about
110 degrees F., since warm water is the more desirable for pur-
pose of dissolving the old or waste papers, and also the che-
icals which these waste papers contain. The supply water for
the beaters is not, however, entirely fresh. The "main" fresh
water supply pump for the mill merely maintains a constant level
in this tank and the amount of water which it supplies is re-
gulated by a float valve in the tank. The greater part of the
water in this tank is supplied from the pit under the wet end of
the paper machine by a centrifugal pump which is generally in-
stalled just outside the walls of the pit, as shown in plate
number 2. In this way water is saved and used over and over
again. This pit water is known to the paper trade as "white
water" and its use and disposal is considered a very important
item. It is termed "white water" due to the fact that it con-
tains a considerable quantity of paper stock (fibres) from the
cylinders vats.
Another important procedure in connection with the handling and use of water in the paper mill and the control of its quality and mineral content, so far as acid and basic salts are concerned, is the testing of the water at the more important points of use. For example, in the beaters, in the vats and in the feed water for the boilers.

The latest and most improved, as well as the most satisfactory type of apparatus for use in making these tests is the "Lamotte Comparator" set. This is a chemical outfit which contains a series of comparative color tubes (same size as ordinary standard 25 c.c. test tube) containing liquids of varying shades of the same color. There are eleven sealed tubes containing solutions of "Bromeresol Purple" of varying strengths so as to produce shades varying from very dark to a very faint purple. These tubes are marked pH 5.0, pH 5.2, and etc., to pH 7.0, which is considered as a "neutral" solution and in color is between a purple and a red. (The darkest purple is the 5.0 solution, and the faintest color is the 7.0 solution). There are also 8 sealed tubes containing solutions of "Phenol Red", varying in shade from light pink at pH 7.2 to dark crimson at pH 6. The set also contains two test tubes for treated samples to be tested, one comparator tube containing distilled water, two test tubes for plain or untreated samples of the water to be tested, two pipettes, one bottle of "Bromeresol Purple" and one bottle of "Phenol Red".

The ranges of colors denote acid or alkaline content of the water according to the following:

- pH 5.0 - 7.0 = Acid solution.
- pH 7.0 = Neutral solution.
- pH 7.0 - 8.6 = Alkaline solution.

The procedure followed in making a water test with the above equipment is as follows:

Three of the empty test tubes are filled with the water which is to be tested. To the contents of one tube is added about 3 c.c. of "Phenol Red" with the pipette. This tube is then shaken well so to thoroughly mix the contents and obtain an even color. Now, the comparator box is provided with a pair of special lenses which form about one-fourth each of the sides of the box, i.e., if the box is 6 in. by 10 in. then the lenses are about 3 in. x 5 in. The inside of the box is provided with drilled holes into which the test tubes and the comparator or pH tubes may be inserted and viewed thru the lens in the side. These holes are arranged so that there are three in the first row directly behind the lens, and three in the second row, which is directly behind the first row. The tubes are inserted as follows:

<table>
<thead>
<tr>
<th>1st row</th>
<th>Tube No.1</th>
<th>Tube No.2</th>
<th>Tube No.3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comparator tube</td>
<td>Treated water to be tested.</td>
<td>Comparator tube</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2nd. row (directly behind 1st)</th>
<th>Tube No.4</th>
<th>Tube No.5</th>
<th>Tube No.6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plain water (untreated)</td>
<td>Distilled water.</td>
<td>Plain water (untreated).</td>
<td></td>
</tr>
</tbody>
</table>
Comparator tubes of varying shades are inserted in positions one and three until a perfect (or nearly so) match is obtained between the color of one of the comparator tubes and the treated water in tube number two, the tubes and their contents being viewed through the lens, and the box being held between the eye of the observer and the light. When a match has been obtained, the pH content of the comparator tube and, hence, of the sample of water tested is read on the label of the comparator tube. If the tube is labeled pH 5.2, this indicates that the water tested is decidedly acid. If the reading is 8.4, this indicates that the water is decidedly alkaline.

The symbol used in the preceding paragraphs (pH) has to do with the control of acidity in industries in which what might be called the "active acidity" is of importance. The active acidity of a solution is often but a small fraction of its total acidity, just as the standing army of a nation is often but a small fraction of its total man power. The symbol "pH" is derived from "Potential of Hydrogen", since the most accurate method for determining the active acidity employs an electrometric apparatus, with a hydrogen electrode. As active acidity falls off, the pH increases, one unit for each tenfold decrease of acidity, thus a pH of 5 means but 10% of the active acidity of a pH of 4, and but 1% of that of a pH of 3. Neutral solutions have a pH of 7, and alkaline solutions greater than 7.

In the paper and textile industries pH control is being widely used. The sizing of paper is a more delicate operation than many paper makers realize. Too little alum (an acid salt used to precipitate the rosin size in the paper stock) means incomplete and inefficient precipitation of the size. Too much alum not only means unnecessary expense, but possibly corrosion of equipment and deterioration of the paper. This can be controlled by a measurement of the pH of the stock as it goes to the machine, as explained above. The pH of the machine water is also very important, and pH control is of value in tub-sizing, coating, coloring, and in "white water" recovery.
DESIGN DATA

for

A SIXTEEN POINT CONTAINER BOARD MILL.

I. Output of Mill
   to be Forty (40) tons of .016 inches caliper Container Board.

II. Trim
   to be Sixty-Six (66) inches.

III. Paper Machine
     to have Five (5) Cylinders.

IV. Location
    to be situated on site indicated on blue print number seven, located near A. T. and Santa Fe R. R. tracks, north of same, at foot of New York Street and on South bank of Kansas or Kaw River.

V. Storage Capacities.

   1. Fuel (to be calculated).

   2. Raw Materials, Two thousand and four hundred tons, (Sixty days supply).

   3. Finished Board - Twelve hundred tons.

VI. Buildings
    to be of reinforced concrete, steel and brick construction.

Note:

The above set of data has been assumed for this particular problem, but a similar set of data, with different quantities and controlling dimensions would be needed for use in the design of any other board mill. The steps in design will be followed through in their proper order and all calculations and working drawings made just as if they were going to be used for construction purposes, i.e., just as if this particular mill were intended to be built in the location designated.
Computations and Design

**Speed or Paper Travel**

Output = 40 tons of .016 in. caliper board weighing 76 pounds per 1000 square feet, per 24 hour day.

Then pounds output per minute = \( \frac{40 \times 2000}{24 \times 60} \)

= 55.5 pounds.

Weight = \( \frac{76}{1000} \) = .076 pounds per sq. ft. or per 144 sq.in.

\[ \frac{55.5}{.076} = 730.3 \text{ sq. ft. output per minute.} \]

The trim is to be 66 inches, then

\[ \frac{66}{12} = 5.5 \text{ feet} = \text{Finished width of sheet.} \]

\[ \frac{730.3}{5.5} = \text{Approximately 133 feet per minute, for paper travel thru machine.} \]

This also equals the surface speed for the dryers, calendars, cylinders and press rolls, of the paper machine.

**The Winder.**

The Cameron Winder is one of the best machines of its kind on the market today, and is built in many styles and sizes, depending upon the requirements.

Blue print number 8 is a detailed drawing of a Cameron winder to be used in this mill. Following are the specifications:

One 72" type 12 Cameron Slitting and Rewinding Machine, 76" Actual face of drums, 60" maximum diameter rewind, with equipment of 5 slitter units complete with spacers, 5 extra slitter wheels only, one 3" diameter collapsible rewind shaft, one power driven slitter grinder and customary accessories, such as wrenches, etc., machine having special arrangements as to riding roll construction and rewind shaft bearings.

Diameter of driven pulley = 24"
Face = 6"

This pulley turns 0.4425 revolutions for each foot of paper travel per minute.

The speed of rewinding and trimming paper from the reel (shown by dotted lines on plate 8) should be about 800 feet per minute for a machine of this size.
Type 12 Winder
72" Wide x 60" Diam. Rewind
Right Hand Drive.

Scale 1/4" = 1'-0"
DRIVE LAYOUT FOR 60" x 72" TYPE 12 WINDER
SECTIONAL DRIVE UNIT REPLACES PULLEY (B) AND BOLT DRIVE USUALLY SUPPLIED.

Scale 1/2" = 1'-0"

THE UNIVERSITY OF KANSAS
DEPARTMENT OF MECHANICAL ENGINEERING
Lawrence, Kansas.

THE DESIGN OF A CONT. BOARD MILL
By: D.T. Roberts

Fall: 1929 - 1930.  Plate No. 9
Then \[ 800 \times 0.4425 = 354 \text{ R.p.m.} \] for the driven pulley. This calculation contemplates the use of a belt drive, from a counter shaft for this machine. The better practice for the use of modern equipment, to the best advantage, is to use a drive as shown on plate number (9) which shows the number 12 Cameron Winder equipped with a General Electric Sectional Driving unit, frame number 103.

Motor Hp. = 25
Motor R.P.M. = 850

Gear Ratio for speed reducer unit of the drive is calculated as follows:

\[
\frac{850}{354} = 2.4
\]

Therefore a gear ratio of 2:1 should be used for this drive, since the motor speed may be easily adjusted to a lower value by use of the regulator device to obtain the required R.P.M. of 354.

**THE REEL.**

Blueprint number ten (10) is a detailed installation drawing of a standard Black-Clawson 40'' x 72'' Reel, equipped with a G. E. Sectional driving unit.

Note: All drives for the "paper machine proper" will be equipped with G.E. Sectional driving units of the proper size and power capacity to facilitate their operation at the best possible efficiency.

The reel shown is of the two drum type and the speed of the drums is calculated as follows:

\[
\begin{align*}
\text{Diameter of wooden drum} & = 12 \text{ inches} \\
\text{Paper speed} & = 133 \text{ feet per minute} \\
\text{Circumference of drum} & = \frac{3.1416 \times 12}{12} \\
& = 3.14 \text{ feet} \\
\text{Req. R.p.m. for drum} & = \frac{133}{\frac{3.14}{12}} = 42.4
\end{align*}
\]

The Sectional driving unit should have the following specifications:

Motor Horsepower = 10

\[
\text{Ratio of motor speed to speed reducer drive shaft (or reel shaft, since the two are coupled together)} = 20:1
\]

\[
20 \times 42.4 = 850 \text{ Approximately R.p.m. for motor.}
\]

Serial number of unit = L D 10.
DIMENSION SHEET FOR SET-UP OF A 40" x 72" BLACK-CLAWSON REEL WITH G.E. SECTIONAL DRIVING UNIT

Motor = 10 H.P. at 850 R.P.M. - Ratio of speed
Reducer gears = 2 to 1.

Scale 1/2" = 1'-0"
Calendar Stacks.

Blueprint number eleven (11) is an installation drawing of calendar stack number one (1). Stack number two (2) is identical with stack number one except as regards the diameters of the top and bottom rolls. Stack number one contains five (5) 14 inch diameter rolls; bottom roll crowned .005 inches. Stack number two contains five (5) rolls; three middle rolls are 14" and top and bottom rolls are 16" in diameter. The bottom roll is crowned .005 inches. These rolls are of solid cast steel. The bottom rolls in each case are the drivers for the remainder of the stack, as shown on the print. The pressure between the rolls governs the caliper or thickness of the paper passing thru the stack, hence, a series of levers equipped with weights is provided on either end of the stack to facilitate varying the pressure on the sheet and therefore the thickness of the sheet, to meet the requirements as to caliper.

Print number (11) also shows the Sectional driving unit for the two stacks. Both stacks are driven with one unit by using a mutual set of bevel gears, a clutch (for stack number 2) and a cross drive shaft, as shown. The clutch must be provided so that the stacks may be driven independently, to provide for repairs, etc.

The speed of stack number one (1) is calculated thus,

Diameter of bottom roll = 14 inches.
R.p.m. for bottom roll = \[ \frac{133 \div 3.1416 \times 14}{12} \]

= 36.3 approximately.

Ratio of bevel gears for stack number one (1)

\[ \frac{71}{36.3} = 1.96 \]

Using sectional drive unit, serial number 103, 25 horsepower, 850 R.p.m. of motor, the 12:1 ratio between motor speed and speed reducer drive shaft should be used.

\[ 12 \times 71.0 = 850 \text{ R.p.m. which is speed specified for this motor.} \]

The speed of stack number two (2) = \[ \frac{133 \div 3.1416 \times 16}{12} \]

= 31.6 R.p.m.

R.p.m. of speed reducer shaft = 71

Ratio of bevel gears for cross shaft to stack number two (2) = \[ \frac{71}{31.6} = 2.25 \]

Dryer Unit:

Note: Referring to blueprint number two (assembly view of
a mill it will be noted that as regards steps in design, the writer has chosen the delivery end of the paper machine as a point of beginning and from said point worked backward toward the process end of the plant. The reason for this procedure is almost self evident, but may be best explained as follows:—

The size of the finished plant together with all of the process machinery, storage, power, etc., is based on a specified or assumed output (in this case 40 tons per 24 hour day) and since this output is measured at the delivery or finish end of the paper machine, then this point is the logical one from which to begin the design—hence working backward toward the process and power end of the plant.

The accompanying drawing, number twelve (12) shows a plan and elevation of the proposed dryer part, together with detail sketches of gear drives, driving unit for the entire dryer part, the dryers, the frame (supporting) and the steam handling equipment. The steam is to be supplied to the dryers by the Farnsworth System shown in detail on print number 12. No. 1 wet end dryer draws its steam supply from the syphon pipes of the next four dryers through the separator. The four dryers of the next section draw their steam supply from the syphon pipes of the next ten dryers through the separator—these ten dryers and the five dryers on the two sections heretofore mentioned make a total of fifteen dryers, and all drawing their steam from all the balance of dryers on the large dry end section through a separator.

The cold wet paper passing over the wet end dryer naturally condenses great volumes of steam, thus causing a drop in pressure and making the steam blow through the syphon pipes in great volumes at a very high speed, thus insuring high circulation of steam in each dryer with an absolute removal of all air to the final collecting chamber number 1 dryer for extraction and also all water, even that lies below the end of the syphon pipe and is all drawn through the various water seals controlling the pressure drops from chamber to chamber until it is finally collected in the wet end final receiving chamber. Here it is drained to a Farnsworth separator and drainage pump unit, to drain and pump the condensate back to the boilers, or to the feedwater heater unit.

The separator contains a series of tapered nozzles and baffle plates. The nozzles speed up the steam and impinge it against the baffle plates. It expands and is forced back through another nozzle. The steam flows back and forth through nozzles, until, when it has passed completely through the separating unit, it is absolutely dry. The legs shown on the separator contain a pressure regulating water seal which limits the drop in pressure to not over two pounds. This insures definite drop in pressure that causes the high velocity of steam from the syphon pipes.

The action which takes place in a dryer may be explained as follows:—Steam is supplied to dryers at a pressure of about 40 pounds gage. As shown in the sketch (print No. 12) the paper comes in contact with approximately two-thirds of the surface of each dryer. On the upper dryers, this paper contact is at the point where the dryer shell is free of water and maximum heat transfer takes place. On the bottom dryers, however, one-half of this paper
contact is the portion of the dryer covered with an inch or more of water. Where one inch of water lies on the dryer shell, the heat transfer is only one-eighth as great as where the shell is dry. If we assume that the top dryers are 100 per cent efficient, then one-half of the bottom dryer is 50 per cent efficient and the other half is but 5 per cent efficient. The overall efficiency of the bottom dryer is then but 56 per cent of the top dryer. The total machine efficiency then drops to but 78 per cent of what it would be if all water was removed. The Farnsworth system removes this inch or one and one-half inches of water from the dryers and hence obtains the maximum efficiency from the dryers.

The Dryer Part shown on print No. 12 is of the Black-Clawson design, standard double deck type, mounted on standard cast iron side frames of the channel type. The dryers are 36 inches in diameter by 72 inches face, and set up in two sections, as shown. The dryers are gear driven, the gears being of the double helical type, to eliminate back lash, and hence reduce paper breaks to a minimum, and the dryer journals (6 in. in diameter) are mounted in heavy duty Hyatt roller bearings to reduce power necessary to rotate the dryers. Both sections are driven thru a pinion gear, as shown, mounted on a drive shaft, coupled to the drive shaft of a speed reducing unit which is a part of a General Electric sectional driving unit.

The speed of the dryers, the gears and, etc., are computed as follows:

\[
\begin{align*}
\text{Paper travel} & = 133 \text{ feet per minute.} \\
\text{Diameter of dryer} & = 36" \text{ (standard).} \\
\text{Circumference of Dryer} & = \frac{36}{12} \times 3.1416 \\
& = 9.42 \text{ feet.}
\end{align*}
\]

\[
\frac{133}{9.42} = 14.12 \text{ R.p.m. for dryer.}
\]

\[
\begin{align*}
\text{Motor R.p.m.} & = 850 \\
\text{Ratio of motor speed to speed reducer drive shaft} & = 25:1 \\
\frac{850}{25} & = 34 \text{ R.p.m. for slow speed shaft, or pinion shaft.}
\end{align*}
\]

The number of dryers required on a machine of this size (40 tons capacity) is calculated as follows:

One inch of dryer face per 100 dryers (36 inches in diameter) will dry one ton of paper in 24 hours. (standard for container board).

\[
\begin{align*}
\text{Width of paper} & = 66 \text{ inches.} \\
\text{one dryer will dry} \frac{1}{100} & = 0.01 \text{ tons per 1 inch of face.}
\end{align*}
\]

Output is to be 40 tons,

\[
\frac{40}{0.01} = 4000 \text{ dryers required to dry 40 tons,}
\]

of paper per one inch of dryer face.
Since width of paper = 66 inches, then
\[ \frac{4000}{66} = 61 \] (approximately) dryers required, to dry 40 tons of paper 66 inches wide, in 24 hours.

Black-Clawson recommends a 75 horsepower driving unit to operate a dryer unit of this size. This unit is shown on print number 12.

Horizontal distance from center of bottom dryer to center of top dryer, as shown, is 21 inches. Vertical distance from center of bottom dryer to center of top dryer is \( = \) to 33\( \frac{1}{2} \)", as shown.

The diagonal (direct) distance from center to center of succeeding dryers is calculated as follows, and is equal to the pitch diameter of the gears required to make the drive continuous from the pinion to the end dryer on each section:

\[
\text{Diagonal distance} = \sqrt{(33.06)^2 + (21)^2}
\]
\[ = \sqrt{1092.3 + 441} \]
\[ = 39.157 \text{ inches.} \]

Using a circular pitch of one inch, the diametral pitch \( = \frac{3.14}{\frac{D}{2}} \) or \( 3.14 = \frac{N}{39.152} \) where \( N \) = number of teeth for the dryer gear, or \( N = 123 \) teeth.

Since R.p.m. of pinion gear \( = 34 \) Let \( X = \) Number of teeth in pinion.

Then, \[ \frac{34 \times X}{123} = 14.12 \text{ R.p.m. for dryer.} \]
\[ \frac{34X}{34} = 1736.3 \text{ or } X = 51.03 \text{ teeth.} \]

A 51 tooth pinion gear will be used.

Circular pitch \( = 1 \text{ inch.} \)
Pitch diameter \( = 16.254 \text{ inches (approx. 16\%)} \)
Face of gears and of pinion \( = 6 \text{ inches.} \)

"Conechow" double helical gears will be used throughout.

The distance from center of pinion to center of first dryer on each section \( = 27.693 \text{ inches, as shown on print.} \) Total length of dryer section from center of first dryer to center of sixty-first dryer \( = 107 \text{ feet and 10 3/8 inches.} \) The remainder of the dimensions are as shown on the print.

Steam for Dryers.

Volume of one dryer \( = \frac{V}{4} \times \frac{d^2}{x} \times \frac{72}{12} \)
\[ = \frac{3.14 \times 27}{2} \]
\[ = 42.5 \text{ cubic feet.} \]

Volume of one pound of steam at 40 pounds gage pressure and 287 degrees F.
\[ \frac{42.5}{7.5} = 5.65 \text{ lbs. of steam required to fill dryer.} \]
It is almost impossible to predetermine the actual condensation per unit of time per dryer per any given installation. This is usually based on actual figures determined from measurements made on actual installations operated under similar conditions and in mills producing the same kinds of board.

Condensation per dryer per hour for a 40 ton mill with a dryer surface speed of 153 feet per minute = 2.5 gallons per dryer, from actual data.

\[ 2 \frac{1}{2} \times 8 \frac{1}{2} \times 12 = 20.8 \text{ pounds of steam required per hour, per dryer.} \]

\[ 61 \times 20.8 = 1270 \text{ pounds per hour for 61 dryers, also,} \]

\[ \frac{20.8}{5.45} = 3.8 \text{ dryers of steam will be evaporated per hour, per dryer, or} \]

\[ 61 \times 3.8 = 232 \text{ dryers (total) of steam will be evaporated per hour for the entire machine.} \]

\[ (232 \times 5.45 = 1270 \text{ lbs. per hr. for 61 dryers }) \text{ check.} \]

Wet End Section of Paper Machine.

Blueprint No. 13 shows an elevation of the "Wet End" of a Black-Clawson - 5 cylinder paper machine. This part of the machine operates as before explained in conjunction with the dryer part just described. The distance, as shown on the print (413) from the center line of the second large press to the center line of the first (wet end) dryer is 8 feet and 60 inches. The first and second large presses are composed of two 20 inch diameter rolls each. The bottom roll in each press is crowned .025 inches.

The second press is driven thru a coupling by a 0. E. sectional driving unit as shown on the print. The first press is driven by a chain and sprocket drive from the second press drive shaft, as indicated. The first and second "Baby" presses are driven from the first large press drive shaft by means of flanged pulley and belt drives as shown. The width of the pit under the wet end of the machine is the same as that under the dryer part, namely, 72 inches. The distance between frames of wet end part = 37 1/2 inches.

The calculations for the wet end driving unit are as follows:

- Diameter of large press rolls = 20 inches.
- Circumference of large press rolls = \( \frac{133}{50} \times 20 = 5.25 \text{ feet.} \)

\[ \frac{133}{50} \times 20 = 25.4 \text{ R.p.m. for first and second presses.} \]

If motor makes 350 R.p.m. then ratio of gears for speed reducer = \( \frac{350}{25.4} = 34 \text{ approximately.} \)

A 5 cylinder, 30 inch, machine of this type (Black-Clawson) with 20 inch x 80 inch press rolls, two whippers and 14 inch couch rolls requires about 75 horsepower for driving. Therefore, the General Electric Sectional Drive No. 125, with 75 horsepower motor and gear ratio of 34 to 1 will be used.

The balance of the presses, felt rolls, couch rolls, and cyli-
ders will be pulled by the top and bottom felts, as per common practice. The cylinder vats are of wood construction with cast iron ends. Each cylinder vat is equipped with a fan pump as shown on the print. The standard size of pump for a 36 inch cylinder is a Number 6, with a 6 inch discharge and an 8 inch suction. At a head of fifteen feet and R.p.m. of 495 this pump will throw 860 gallons per minute.

The function of this pump is to produce a suction in the cylinder vats so that the paper fibres will cling to the surface of the cylinder. The amount of water entering the cylinder vat per minute may be determined as follows:-

Each cylinder vat is equipped with a 1 1/2 inch shower pipe which throws about 153,000 gallons of clear water per 24 hours thru the face of the cylinder. (This value was determined by actual measurement on a 1 1/2 inch shower pipe in a 40 ton board mill).

\[
\frac{153,000}{24 \times 60} = 106 \text{ gallons per minute, delivered by shower to vat.}
\]

The stuff pumped into the vat contains about 1/4 of one per cent paper stock by weight.

\[
\frac{40}{5} \times 2000 = 8 \text{ tons of paper per cylinder per day.}
\]

\[
\frac{16000}{24 \times 60} = 11 \text{ pounds paper per minute.}
\]

\[
\frac{40}{11} \times 0.0025 = 4,400 \text{ pounds water per minute mixed with paper stock.}
\]

Water carried away in paper \[ = 5 1/2 \text{ pounds per minute (50\%) which is negligible.}\]

\[
\frac{4400}{8.53} = 530 \text{ gallons per min. (approximately)}
\]

\[
530 \text{ plus } 106 = 636 \text{ gallons per minute total.}
\]

A good average value to use for this would probably be 650 gallons per minute. Of this amount, 50 gallons overflows to the pit as pit water and 600 gallons per minute is drawn from the vat by the fan pump.

Referring to Appendix II :-

\[
Q_1 = 860 \text{ gallons per minute.}
\]

\[
N_1 = X \text{ R.p.m.}
\]

\[
Q_2 = 600 \text{ gallons per minute. (required)}
\]

\[
H_1 = X \text{ feet total head.}
\]

\[
N_2 = 500 \text{ r.p.m. (assured).}
\]

\[
H_2 \text{ will be equal to 15 feet.}
\]

\[
\frac{Q_1}{Q_2} = \sqrt{\frac{H_2}{H_1}} = \frac{N_1}{N_2}
\]

\[
860 = \frac{M_1}{500} \quad N_1 = 716 \text{ R.p.m.}
\]

\[
600 \quad \frac{500}{500} \quad H_1 = 30 \text{ feet.}
\]
This would require a No. 6 pump (single stage) with 6 inch discharge and 8 inch suction. The motor required would need to be 5 horsepower, at 1800 r. p. m.

\[
\text{Ratio motor to speed reducer} = \frac{1800}{500} = 3.6 \text{ or a ratio of 4 to 1.}
\]

The G. E. sectional drive shown is No. L. D., Size No. 5.

There are two whippers, as shown, and each whipper is driven by a one horsepower motor, thru a belt drive at a rate of 1800 or approximately 4 to 1, where the motor r.p.m. = 1800.

Save All.

Referring to plate 14.

The white water flows from the wet end pit thru the overflow pipe as shown to the "Save-all". The overflow to the pit from the cylinder vats = 5 x 50 = 250 gallons per minute.

There are also two other showers, one on each whipper, delivering 106 gallons of water per minute each, or 2 x 106 = 212, say 200 gallons per minute.

\[
250 \text{ plus } 200 = 450 \text{ gallons per minute } = \text{total pit water.}
\]

The centrifugal pump required to handle this water (and probably 50% excess) would be a 4" American Pump -- 4 inch discharge, 6 inch suction -- 595 R.p.m. @ 430 G.p.m. Ratio of motor speed to pump speed (direct driven thru back gears, motor and pump on one base) = \[
\frac{1800}{430} = 3.75 \text{ or approximately 4 to 1.}
\]

A 5 horsepower motor will be required to drive this pump.

Total head = 20 feet maximum. The pump transfers the stock (saved from the pit) to the beater stuff chest.

The operation of the Bird "save-all", shown on print No. 14 is as follows:-

The incoming white water enters the vat "A" through inlet "B" and filters through cylinder "C" which revolves slowly in the direction shown by the arrow. The filtered water discharge at one end of the cylinder opposite the drive. The stock gathered on the face of the mould is driven off as it passes over the shower "D" and falls into compartment "E" from which it flows to the pump.

The speed of the cylinder varies with changes in the volume and consistency of the white water furnished. It is controlled by a float which follows the level of water outside the mould.

In case an excess of water floods the save-all an overflow is provided at "F" which discharges into the sewer, as shown, instead of on the floor.
Elevation of Cylinder Vats

White-Water Pit

Sectional Diagram of A Bird No 5
SAVE-ALL

THE UNIVERSITY OF KANSAS
DEPARTMENT OF MECHANICAL ENGINEERING
Lawrence, Kansas.

THE DESIGN OF A CONTAINER BOARD MILL ~
By: D. D. [Signature]

Fall-Spring 1928-30
Plate No. 14
Bird Save-All Specifications.

<table>
<thead>
<tr>
<th>Overall Dimensions</th>
<th>No. 5 Save-All</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>11 Ft. = 11 inches.</td>
</tr>
<tr>
<td>Width</td>
<td>6' = 10&quot;</td>
</tr>
<tr>
<td>Height</td>
<td>4' = 10&quot;</td>
</tr>
<tr>
<td>Dimensions of Mould</td>
<td>42&quot; Diameter.</td>
</tr>
<tr>
<td>Dimensions of Mould</td>
<td>100&quot; face.</td>
</tr>
<tr>
<td>Weight</td>
<td>7200 lbs.</td>
</tr>
<tr>
<td>Dimensions of Pump</td>
<td>(Inlet = 5 inches.</td>
</tr>
<tr>
<td></td>
<td>(Discharge = 4 inches.</td>
</tr>
<tr>
<td></td>
<td>(Face = 2½ inches.</td>
</tr>
<tr>
<td></td>
<td>(Diameter = 12 inches.</td>
</tr>
<tr>
<td>Power Consumption</td>
<td>One-horsepower.</td>
</tr>
</tbody>
</table>

Note:
A one H.P. motor will be used to drive the save-all. The capacity of a No. 5 save-all is 350,000 to 400,000 gallons in 24 hours, which is sufficient for a 72 inch, 5 cylinder machine.

Screens

Three "Bird Rotary Screens" of 15 tons in 24 hours capacity each will handle the stock necessary to supply the 5, 36" cylinders as shown on print number 13. This screen is automatic in operation and requires about 10 x 20 feet of floor space, and 8 feet of head room. It requires about a 20 horsepower motor for driving -- a back gear drive has proven very satisfactory.

Jordans

Jordans are rated for capacity in tons per hour. Since the capacity of this mill is to be 40 tons and if two "one ton" jordans were used then 2 x 24 = 48 tons = actual capacity of the two jordans. The better practice is to provide a jordan for each separate stock treated in the beaters, therefore since there will be three kinds of stock, "Inner liner," "outer liner" and filler stock, then there will need to be 3 jordans, one for each stock. This will mean that each jordan will handle amounts of stock as follows:

1. Outer liner. Based on 1/3 the thickness of the sheet or 1/3 x 40 tons = 13 1/3 tons per 24 hours.
2. Inner liner - same as outer liner = 13 1/3 tons per 24 hours.
3. Filler - same as liners = 13 1/3 tons per 24 hours.

A jordan of this size (one ton) requires a 150 horsepower motor for powering. This is the size of motor recommended by the Shartle Brothers Machinery Company, Middletown, Ohio, builders of the Miami Jordan. This jordan is equipped with a base long enough to accommodate a 150 h.p. motor, direct connected by a coupling. The entire length of the jordan and drive combined is about 22 Ft. 6 inches. The width equals about 4 ft. = 0 inches, and head room required for the jordan and necessary piping equals about 8 feet. The inlet and outlet pipes are each 6 inches.

In an actual installation, one of these jordans, with a ca-
Capacity of one ton per hour, and actually handling about \( \frac{36}{3} = 12 \) tons in 24 hours or \( \frac{12}{24} = 1/2 \) ton per hour used power as follows:

\[
\text{35,500 Kw. in 540 hours or } \frac{35,500}{540} = 66 \text{ Kw. per hour.}
\]
\[
66 \times 1000 = 66,000 \text{ watts per hour. } \frac{66000}{746} = 90 \text{ H.P., approx. required to pull the jordan. This was a direct connected, 150 H.P., G.E. induction motor operating on 440 volts and 201 amperes, 60 cycles, alternating current. The R.p.m. of the jordan should be about 375 at full load, for best results.}
\]

### Beaters

A 40 ton mill, making 16 point test liner requires 3 beaters, one for inner liner, one for outer liner and one for filler stock. Beater stock, when ready to dump into the chest is 5 per cent paper pulp and 94 per cent water. This means that for each ton of paper stock in the beater there will be 4000 gallons, or 4000 x 8 1/3 = 33,320 pounds of water. Each beater will need to handle 40/3 = 13 1/3 tons of paper stock (plus amount required for shrinkage) per hour. Blue print number 15 shows a plan and an elevation of a Dilts, Right Hand, 62" x 54" New Type Extractor Beater, which is equipped to handle a minimum of 20 tons of paper stock with the roll turning with a surface speed of 1300 feet per minute (recommended by the Dilts Beater Company), Dayton, Ohio. These beaters are generally equipped with a motor and belt drive. The horsepower required at full load, that is, with the roll let down for hard grinding, is about 100 H.P.

The drive is calculated as follows:

\[
\text{Roll diameter } = 62 \text{ inches.}\]
\[
X = \text{R.p.m. for roll } = 1800.
\]
\[
\frac{62 \times 3.1416 \times X}{5.16 \times 3.1416} = 111 \text{ approximately.}
\]

The beater roll pulley is 18 inch face x 72 inches diameter. If the motor turns 375 R.p.m. then the diameter of the motor pulley will be found as follows:

\[
\frac{111 \times 6}{X} = 375 \text{ or } X = \text{Diam. of motor pulley } = \frac{111 \times 6}{375}
\]

Motor pulley dimensions = 18 in. face x 21 in. diam.

### Stuff Chests:

A stuff chest should be of sufficient capacity to contain about 4 beaters of stock. This would be determined as follows:

The capacity of a one ton beater with a 6 percent furnish

\[
= \frac{2000}{} + 8 1/3 = 4000 \text{ gallons.}
\]

Since there are 7 1/2 gallons per cubic foot of furnish, \( 4 \times \frac{4000}{7.5} = 2140 \text{ cubic feet for volume of the stuff chest. The chest should be proportioned so as to occupy the smallest possible floor space. Assuming that the ceiling of the chest room is 15 feet, the chest could be proportioned as follows:}

Allowing the full 15 feet between floors for the depth of the
cbeart, then if the inside dimensions were 15 feet depth \( \times \) 15 feet length \( \times \) 9 1/2 feet width then the cubical capacity would be as required, or 2140 cubic feet, since \( 15 \times 15 \times 9.5 \approx 2140 \). There would need to be three chests of this size, one for the filler stock, then one for the inner liner, and one for the outer liner. This would meet the requirements for the beaters. There should also be a chest for each Jordan engine or a total of three chests for Jordan stock. A Jordan chest should be of about two beaters capacity, namely 8000 gallons or \( 8000 \div 7.5 \approx 1066 \) cubic feet. Again allowing 15 feet for the depth of the chest, the length and width could be as follows:

\[
15 \times 10 \times 7 \frac{1}{2} = 1030 \text{ cubic feet}, \quad \text{or} \quad 15 = \text{depth} \\
10 = \text{length} \\
7 \frac{1}{4} = \text{width}.
\]

Also, each chest should be equipped with an agitator for paper circulation and mixing of the stock, i.e., to prevent settling to the bottom of the chest and to maintain the proper consistency, namely, about 6 percent paper stock by weight. The agitators for the larger chests will require a 3 horsepower motor each for driving and those for the smaller Jordan chests require 2 horsepower motors each for driving. This would be a total of 3 - 3 horsepower motors and 3 - 2 horsepower motors with gear drives included.

The accepted design for a concrete stuff chest is as follows:

(a) The walls should be approximately 4 inches thick, reinforced with 1/2 inch vertical rods spaced 8 inches on centers and 3/8 inch horizontal rods spaced 8 inches on centers, all rods to be properly tied at the crosses. The horizontal reinforcing to extend around the corners of the chest walls not less than 2 1/2 feet, and the vertical rods to bend and extend into the floor slab not less than 1 1/2 feet.

(b) The floor slab should be of 6 inches thickness, resting on a firm base of sufficient compressive strength to support the load of the chest plus its contents. It should be reinforced with 3/8" rods spaced 8" both ways and properly tied at the crosses.

(c) The openings in the chest walls (at the approximate center, lengthwise, and approximately 1/2 the distance from floor to the top of the chest) to accommodate the agitator shaft should be provided with steel bearing plates and stuffing glands to prevent leaks.

The location of the chests will be as shown on the floor plan and elevation of the mill.

**Stuff Pumps**

There will need to be a stuff pump of the centrifugal type to pump stock from each beater chest to its Jordan engine and also a pump to handle the stock from each Jordan chest to the screen head boxes, as shown on plate number 2. As these pumps will need to operate continuously in order to provide a constant supply of paper stock to the paper machine, there will necessarily need to be a bypass provided at each Jordan to return excess beater stock to the beater chests and, also at the screen head boxes to return excess
jordan stock to the jordan chests. The capacities of the pumps are determined as follows:—

(a). Stock required at the cylinder vats = assumed output for the mill plus shrinkage plus estimated percentage of paper stock in the pit or white water as pumped thru the save-all and back to the beater chests.

1. Assumed output of mill = 40 tons (6% moisture air dried)
2. Shrinkage = 6 percent
3. Stock in white water = 1 percent of output per 24 hrs.

then paper stock actually pumped to the cylinder vats per 24 hours = 1.03 x 40 x 1.01 = 43.63 tons. The mixture (stuff) of stock and water handled by the pumps is watered excessively, purposely to facilitate better pumping action. The percentage of stock in the chest mixture is about (.03) 3 percent. The stock plus water handled, then is calculated thus:

Let X = Weight of water plus stock,
then .03 X = 43.63.

or X = \( \frac{43.63}{.03} \)

= 1455 tons water plus stock per 24 hours.

\[ \frac{1455 \times 2000}{8.33} = \frac{2910000}{8.33} = 349,340 \text{ gallons per 24 hours to be handled by each set of 3 pumps. Each pump (jordan or beater) will then need to handle --} \]

\[ \frac{349,340}{3} \times \frac{1}{24} = \frac{116446}{24} = 4852 \text{ gallons per hour.} \]

Good practice is to pump about 3 times this volume of stuff in order to be assured of plenty of stock at the Jordans, since a certain percentage of the jordanned stock is rejected by the screens and returned to the jordan chests.

then, \( 3 \times 4852 = 14,556 \) or approximately 14,600 gallons per hour = capacity for each pump, or \( \frac{14600}{60} = 243 \text{ gallons per minute} \) --- use 250.

The speed for a stuff pump is necessarily lower than that for a pump of the same capacity designed to handle water or some similar fluid, due to the friction of the paper stock in the fluid mixture, and the extra power required to handle the stock at the heads encountered in a paper mill.

The American Pump Company Manufactures a direct driven (motor and gear drive thru a speed reducer) stuff pump which is very efficient. Choosing the most popular size of pump for this size of mill, as regards suction and discharge pipes (for friction considerations) namely, a number six (6) pump, with 6 inch suction and 5 inch discharge, the rated capacity is (referring to catalog No. 149) 1000 gallons per minute at 600 r.p.m. and a total head of 25 feet. B.H.P. = 11.0

The required head will be approximately 25 feet.
The required G.P.M. will be 250.
Calculations will be made for R.P.M. as follows:-

Referring to Appendix II.

\[
\begin{align*}
\frac{Q_1}{Q_2} &= \frac{N_1}{N_2} \\
Q_1 &= 1000 \text{ g.p.m.} \\
Q_2 &= 250 \text{ g.p.m.} \\
P &= 11.0 \text{ H.P. Let } N_2 &= X \text{ R.p.m.} \\
\frac{Q_1}{Q_2} &= \frac{1000}{250} = \frac{600}{X} \\
\text{Then } X &= \frac{600 \times 250}{1000} \\
&= 150 \text{ R.p.m. for the pump.}
\end{align*}
\]

Then since the head H will need to be equal to H, namely, 25 feet, the power, P will not need to be greater accordingly than P in order to compensate for the drop in speed from H to H as shown by the calculations below:-

Let \( P_2 = X \)

\[
\frac{P_1}{P_2} = \frac{11.0}{X} = \sqrt[3]{\frac{H_1^3}{H_2^3}} = \sqrt[3]{\frac{25^3}{25^3}} = 1
\]

\[ X = P_2 = P_1 = 11.0 \text{ H.P.} \]

If driven through speed reducers as suggested above, 10 h.p. motors will drive these pumps very efficiently. There will need to be six motor driven stuff pumping units to handle the paper stock, as outlined above.

**Beater Water Tank**

The cubical capacity of the beater water heating tank should be approximately equal to that of three beaters. Since each beater holds 4000 gallons of water, when furnished, then \( 3 \times 4 = 12000 \) gallons equals capacity of the required tank.

Since there are 7.5 gallons per cubic foot, then,

\[
\frac{12000}{7.5} = 1600 \text{ cubic feet volume for the tank.}
\]

Cylindrical vertical steel tanks are generally used for this purpose, and a convenient size for the tank would be calculated as follows:

\[
V = h \times \frac{3.1416 \times d^2}{4}
\]

\( V \) = volume and \( h \) = height or depth of tank (vertical tank)

The volume of the tank should be increased about 25% to allow for the volume of the heating coils, etc., or \( 1.25 \times 1600 = 2000 \text{ cu.ft.} \) for tank, required.

Choosing: \( h = 13 \text{ feet} \) and \( d = 14 \text{ feet} \)

\[
V = 13 \times \frac{3.1416 \times 14.0 \times 14.0}{4} = 2000 \text{ cubic feet.}
\]
The tank should be covered with a removable steel cover, insulated all over with a heat retaining substance, such as asbestos and should contain sufficient heating coils (steam) to maintain a beater water temperature of 125 degrees Fahrenheit — which is the most favorable temperature for good beating results. These tanks are generally made of 1/4 inch steel for the shell, 3/8 inch steel for the bottom and a 5/16 inch steel top. They are equipped with an overflow near the top and a float valve to maintain the level of the water so that there will always be sufficient water to fill three beaters.

The heating coils are generally supplied with low pressure or about ten pounds gage. The size and length of heating coils required to maintain the above temperature in 12,000 gallons of water are determined as follows:

Initial temperature of tank water will be assumed as 60 degrees Fahrenheit.

<table>
<thead>
<tr>
<th>Volume of water</th>
<th>12,000 gallons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight of water</td>
<td>5.34 x 12,000  = 100,000 pounds</td>
</tr>
<tr>
<td>Specific heat of water</td>
<td>1.00</td>
</tr>
<tr>
<td>Heat required to raise the temperature of water from 60 degrees Fahrenheit to 125 degrees Fahrenheit,</td>
<td>100,000 (125 - 60) x 1.00 = 6,500,000, B.t.u.</td>
</tr>
</tbody>
</table>

From Steam Table (Table No. 4, H. & V. Heating and Ventilating Hand Book by Hoffman, for saturated steam) —

For gage pressure of 10 lbs. per sq. in., (25 lbs. abs. approx.)

temperature of steam = 240 degrees Fahrenheit.

| Volume of steam in cu. ft. | 16.30 |
| Heat content | 1160 B.t.u. per lb. |

For an output of 40 tons per day there will need to be 43.6 tons of beater stock per day and 43.6 x 4000 x 8.33 = 1,452,750 lbs. of beater water per 24 hours.

this will be \( \frac{1452750}{12000 \times 8.33} \) = 14.5 tanks of water required, per 24 hours, or \( \frac{14.5}{24} \) = 0.60 tanks per hour.

Using a value of 1 tank per hour, this will mean that 6,500,000 B.t.u. will need to be supplied per hour by the steam in the heating coils.

Note:

The following method of computing the amount of pipe required for heating the tank water is taken from the American Radiator Company handbook (21st. Edition), pages 276 and 277. Title of paragraph is "Heating Power of Brass and Iron Pipe Lying Horizontally in water Storage Tanks."

| Heat required per hour | 6,500,000 B.t.u. |
| Total temp. rise desired | 65 degrees per hour, |
| temp. of steam at 10 lbs. pressure | 240 degrees Fahrenheit. |
Mean temp. of water $= \frac{185}{2} = 93$ degrees, approx.
Mean temp. difference between steam and water $= 147$ degrees.

From the chart page 277, for a temperature difference of 147 degrees, the B.t.u. transmitted per square foot of pipe per hour would be approximately 30,000, and the condensing power would be 32 pounds of steam per square foot per hour.

The total square feet of wrought iron pipe required will then be $= \frac{6,500,000}{30,000} = 216.6$ or approximately 217 sq. ft.
The condensation per hour would be $= 217 \times 32 = 695$ pounds.

Referring to appendix III, the length of a 2 inch pipe for an area of one square foot $= 1.603$

then, $217 \times 1.603 = 349$ feet of 2 in. pipe required neglecting fittings. Allowing about one percent for fittings the length of 2" pipe required would be $.99 \times 349 = 346$ feet.

Note:
The table used (page 277) allows for bad water and fouling and pitting of pipes by using only 50% of the actual condensing power of the iron pipe.

Allowing 8 feet as the length of the coils -- they could be made up of $\frac{346}{8} = 43$ pieces of 2 inch pipe, using coil bends for returns.

Head Boxes.
The head box is made of 2 inch cypress and divided into as many sections as there are cylinders on the machine, or in this case, 5 sections. The entire box is made about 10 feet long x 4 feet deep x 4 feet wide. Each cylinder supply section is then approximately 2 feet x 4 feet x 4 feet. Stock is pumped directly from the Jordans to the head box. There will then be one section for outer liner stock, one for inner liner stock and three for filler stock. An overflow is provided from each section of the head box to its respective Jordan chest to carry off the surplus stock supplied to the head box by the Jordans. The head box is situated as shown on the mill plan.

Water Supply.

One pump of the centrifugal type will be used to supply total water to be used by the proposed mill. The pump will be located as shown on the plan and elevation of the mill and the water supply will be the Kaw River, as shown. The size of pump necessary to furnish total water required by the mill is determined as follows:

(a) Total shower water $= 7 \times 106 = 742$ gallons per minute
   (153,000 gallons per shower per 24 hours.)
(b) Beater Water. The pit water pumped through the save-all $= 450$ gallons per minute, approximately. Only part of this water is pumped to the beater water supply tank, about $43.6 \times 4000 = 174,400$ gallons per 24 hours $= \frac{174,400}{24 \times 60} = 121$ gallons per minute.

The balance of the pit water rejected by the save-all returns to the river via the sewer. Hence, no fresh water is required by the beaters for furnishing purposes.

(c) Boiler Feed water. It will be necessary to estimate the amount of feed water required since the boiler horsepower required has not yet be determined. A 40 ton mill of this type (from actual statistics) powered by turbo generator units supplied with superheated steam uses approximately 60,000 gallons feed water per 24 hours, or

\[
60,000 \div 24 \times 60 = 42 \text{ gallons per minute nearly.}
\]

Since the condensation from the dryers amounts to approximately 1270 lbs. per hour, or

\[
\frac{1270}{60 \times 8 \frac{1}{3}} = 2 \frac{1}{2} \text{ gallons per minute, and is used as make-up water.}
\]

and condensed steam from the surface condenser will probably amount to about 30 gallons per minute, then the actual feed water to be supplied per minute by the river pump will be

\[
42 - (30 \text{ plus } 2.5) = 9 \frac{1}{2} \text{ gallons approximately.}
\]

(d) Condensing water. Surface condensers are used in most steam turbine plants, principally for the reason that the exhaust from the steam turbine does not contain oil, and when condensed is an ideal feed water, as it contains no scale-producing matter.

The area of cooling surface of a surface condenser is based on the weight of steam to be condensed per hour, in pounds. This will be estimated as follows:-

Assume that steam consumption of turbine = 22 lbs. per Kw., hr., and that 1000 Kw. will be total power required by mill, then if 3/4 of the total steam supplied to the turbine is exhausted thru the condenser -- 75 x 22 x 1000 = 16500 lbs. steam to be condensed per hour.

One sq. ft. of cooling surface is allowed for every 4 to 8 lbs. of steam to be condensed per hour (Reference: Allen & Bursley - "Heat Engines" - page 242).

Using a value of 6 lbs. per hour the size of the condenser and hence the amount of cooling water required per unit of time will be calculated as follows:-

\[
W = \frac{w(H - (t_3 - t_2))}{t_2 - t_1}
\]

Where,

\[
W = \text{Weight of cooling water entering per minute.}
\]

\[
w = \text{Weight of steam condensed per minute.}
\]

\[
H = \text{Heat (above 32') in the steam entering the condenser.}
\]

\[
t_3 = \text{the temp. of the condensed steam leaving a surface condenser.}
\]

\[
t_2 = \text{final temp. of the cooling water.}
\]

\[
t_1 = \text{initial temp. of the cooling water.}
\]

then,
\[ w = \frac{16500}{60} = 275 \text{ pounds per minute.} \]
\[ H = 1160 \text{ B.t.u. (for pressure of 25 lbs. abs.) est.} \]
\[ t_1 = 60 \text{ degrees Fahrenheit.} \]
\[ t_2 = 100 \]
\[ t_3 = 150 \]
\[ W = 275 \left( \frac{1160 - (240 - 32)}{100 - 60} \right) \]
\[ = \frac{275 \times 952}{40} = 6545 \text{ pounds of cooling water required per minute.} \]
\[ \frac{6545}{8.33} = 785 \text{ gal. of cooling water required per min.} \]

(c) Miscellaneous water := (estimated).

1. For felt washing, cylinder washing, cleaning, sprinkler systems, heating, flushing beaters, etc., -- 1200 gallons per hr., or 20 gallons per minute.

\[(f) \text{ Total fresh water to be supplied by the river pump} = 742 \text{ plus 9 1/2 plus 785 plus 20} = 1556.5 \]

Use 1557 gallons per minute.

(g) Pump. Estimated head = 50 feet.
(Reference -- A. W. W. Catalog No. 149).

Adding 5 percent to total calculated water to compensate for losses, excess requirements, etc., -- \(1.05 \times 1557 = 1635 \) gallons per minute to be handled by pump.

Referring to Appendix No. 2----

\[ \frac{Q_1}{Q_2} = \frac{N_1}{N_2} \quad \text{and} \quad \frac{P_1}{P_2} = \left( \frac{H_1}{H_2} \right)^3 \]

The American Pump Company (Catalog 149, page 102) lists a centrifugal pump with an 8" discharge and 10" suction discharge to handle 2200 g.p.m. at a total head of 50 ft., when running at 615 r.p.m. and drawing 42 H.p.

Then,
\[ Q_1 = 2200 \text{ g.p.m.} \]
\[ Q_2 = 1635 \text{ g.p.m.} \]
\[ N_1 = 615 \text{ r.p.m.} \]
\[ N_2 = X \text{ r.p.m.} \]
\[ H_1 = 50 \text{ feet.} \]
\[ H_2 = 50 \text{ "} \]
\[ P_1 = 50 \text{ Horsepower.} \]
\[ P_2 = X \text{ "} \]

or,
\[ \frac{2200}{1635} = \frac{65}{X} \]
\[ X = \frac{457}{X} \text{ r.p.m. for req. pump.} \]

\[ \frac{P_1}{P_2} = \frac{50}{X} = \left( \frac{50}{50} \right)^3 = \left(1^3 \right) = 1 \]

or,
\[ X = 50 \text{ h.p. for motor to pull pump at 457 r.p.m.} \]
A No. 8 pump with an 8 inch discharge and a 10 inch suction, running at 457 revolutions per minute will handle 1655 gallons of water per minute and if driven thru a speed reducer with good efficiency will require a 50 H.p. motor for powering, at a head of 50 feet.

Other Pumps.

1. Pump to handle the condensed steam from the surface condenser.

   Weight of water = 275 lbs. per minute (est.)
   \[ \frac{275}{8 \frac{1}{3}} = 33 \text{ gallons per minute.} \]
   Add a possible 50% for overload or \[ 1.50 \times 33 = 50 \text{ g.p.m.} \]

   A 1 1/2" pump - 1 1/2" discharge and 2 inch suction running at 800 R.p.m. is rated to lift 50 gallons of water per minute at a total head of 30 feet. This pump requires a 2 H.p. motor for powering. The condenser discharge should be at least 5 feet above the center line of the pump shaft.

Power Plant.

2. Reel------------------------------------------10.0
3. Calendar stacks--------------------------------25.0
4. Dryer Unit-----------------------------------75.0
5. Wet end of Machine--------------------------75.0
6. Cylinder fan pumps -- 3 at 5 ea.----------------15.0
7. Save-All -----------------------------------1.0
8. Save-All pump--------------------------------5.0
9. Screens---------------------------------------5.0
10. Jordans-- 3 at 150--------------------------450.0
11. Beaters-- 3 at 100--------------------------300.0
12. Agitators-- 6 at 3--------------------------18.0
13. Stuff pumps-- 6 at 10-----------------------60.0
14. River (mill) pump--------------------------50.0
15. Condenser pump motor-----------------------2.0
16. Fuel pump (estimated h.p.)-------------------5.0
17. Monorail hoist motor (raw stock handling)---2.0
18. Monorail hoist motor (finished roll handling)---2.0
19. Miscellaneous power ------------------------20.0
   (felt washers, etc.)

   Total motor H.P.------------------------1160.0

\[ 1160 \div 1.34 = 865 \text{ kilowatts, electrical power required by motors.} \]

Assuming an overall motor efficiency of 85 percent, then \[ 1.15 \times 865 = 995 \text{ kilowatts would be actual consumption by motors.} \]

Adding 5 Kw. for lighting and miscellaneous power, including one percent for line and transformer losses \[ 995 + 5 = 1000 \text{ kilowatts total electrical power to be furnished by the generator.} \]

A 1000 Kw. turbo generator unit is recommended for this plant, the turbine to be of the bleeder or extraction type, since steam for auxiliary purposes such as for drying, heating, etc., must be drawn off at pressures ranging from 40 lbs. gage to 5 pounds gage. 1000 - 995 = 5 Kw. to allow for losses in the generator and take care of overloads.
Assuming a thermal efficiency for the unit of 60 percent and making no allowances at this stage of the calculations for the bleeding process, the steam rate for the turbine will be calculated as follows:

Note:
The steam turbine is recommended as a driving medium for the generator in this proposed plant for the following reasons:

(a) The turbine is adapted to the bleeding process and in a paper mill, large quantities of steam are used for process work, at various pressures.
(b) The steam turbine can utilize a high vacuum to better advantage than a reciprocating engine since in the engine the economical limit of vacuum is about 26 inches of mercury. With the turbine the vacuum is from 27 to 29 inches based on a 30 inch barometer - 23 inches being the best average. This corresponds to a condenser pressure of 2 inches of mercury. Tests indicate that the saving in steam consumption is from 5 to 8 percent for each inch increase of vacuum.
(Reference: Goodenough's Principles of Thermodynamics and Mechanical Engineer's Handbook).

Also, high superheat may be used to better advantage in the steam turbine than in the steam (reciprocating) engine, since there are no rubbing parts in contact with the steam.

Calculations.

1. Assumed thermal efficiency based on Kw. Per Hr. = 50%.

Thermal efficiency = B.t.u. equivalent to 1 Kw. Hr.
heat rate measured in B.t.u. per Kw. Hr.

(Reference: A.S.M.E. Power Test Codes, series 1926.)

or, Thermal efficiency = \( \frac{3412}{w (h_1 - h_2)} \)  where \( w \) = lbs. of steam as supplied per Kw. hr. and \( h_1 - h_2 \) = available heat in B.t.u.

Assuming that:

(a) Steam is furnished at 180 lbs. gage and 560 degrees Fahrenheit (560.0 - 373.1 = 186.9 degrees of superheat).
(b) Condenser pressure is 2 in. of mercury for a 28 in. vacuum.

then, from the Mollier Chart the thermal potential for initial state = \( i_1 = 1302.2 \) B.t.u. and with \( P = 2 \) in. of mercury, the final potential is \( i_2 = 931.2 \) B.t.u.

The available heat ( \( h_1 - h_2 \) ) = 1302.2 - 931.2 = 371 B.t.u.

or, \( .50 = \frac{3412}{371 \times w} \), from which

\[ w = \frac{3412}{.50 \times 371} = 18.5 \text{ lbs. steam per Kw. hr.} \]
2. To increase the value calculated above to 21.0 lbs. steam per Kw. hr., which is in agreement with the steam rate as listed, for this type of turbine under the conditions of temperature and pressure as used above (and taking into consideration the bleeding process), in the "Mechanical Engineer's Handbook" for 1929, and also in Gebhart's "Power Plant Engineering", pages 482 - 486.

**The Turbine - Generator Unit.**

A General Electric Type F - 1000 KW., 60 Cycle Condensing turbine arranged for automatic steam extraction at 40 lbs. pressure and 5 lbs. pressure is recommended for this plant. The 60 cycle generator is of the revolving field type, direct-connected to the turbine and operates at 3600 R.p.m. Bus voltage = 2500 volts.

The turbine is of the impulse type, in which the useful power is obtained from the impact of steam jets on buckets attached to the revolving wheels. The turbine, therefore, consists essentially of a series of bucket wheels on a shaft, each wheel supplied with nozzles, and the whole enclosed in a casing. Each wheel with its nozzles constitutes a stage and each wheel is separated from its neighbors by diaphragms; the number of stages depending upon the size of the unit.

**Other Electrical Equipment.**

1. General Electric Sectional Paper Machine Drive -- which consists of:

   (a). Generator panel with ammeter, voltmeter, exciter, field rheostat, overload relay, line contactor, and single-pole line switch.

   (b). Voltage regulator panel on which is mounted a generator voltage regulator and an exciter voltage regulator.

   (c). Auxiliary control panel on which is mounted the voltmeter and rheostat for the generator voltage regulator; also the rheostat operating mechanism for the generator field rheostat. This panel controls the generator voltage and the speed of the paper machine as a unit.


   (a). A main driving motor for each section of the paper machine (already described and rated on blueprints).

   (b). A speed regulator of the synchronous type for each section of the paper machine. (also described and rated on the blueprints.)

3. Control.

   (a). 1 contactor control panel for each sectional motor.

   (b). 1 starting rheostat for each motor.

   (c). 1 motor operated master switch for each motor.

The contactor panels are of the five point type with definite time limit accelerating relays. The starting rheostat is designed
for 75 percent speed reduction continuously. The motor-operated master switch is of the totally enclosed type and is mounted directly on the control panel and operated from push buttons on the front side of the paper machine.

4. Location of Equipment.

The power unit should preferably be centrally located with reference to the machine to simplify the wiring; and all of the control equipment should be lined up as a single switchboard leaving nothing in the paper machine room, except the motors which drive the various sections of the paper machine and the push buttons which are located on the front side of the machine.

5. Operation.

In starting the paper machine, the turbine-generator set will be running and there will be a proper voltage supply available. Each section of the paper machine may be started up in succession, starting with the press rolls, by merely pressing the button, after which the motor automatically comes up to its full speed or to a speed corresponding to the supply voltage, and the speed regulator is automatically connected to the master generator bus and begins to function immediately.

While each sectional motor may be brought up to its full speed automatically by pressing a button, it is also possible to operate the motor at slow speeds for washing felts, changing wires, or spearing broke.

The individual control of the motors permits of operating any section of the paper machine independently of any other section and at the same time assures an absolute tie-in between the sections when all motors are operating at their full speed.


The master generator set which supplies alternating-current power to the regulators in each section of the machine is controlled from the main generator panel and automatically comes up to speed when the voltage is brought up on the generator.

Voltage.

The generated voltage of 2300 will need to be stepped down to 440 volts for transmission to the various motors to facilitate safety and also from an economical standpoint - as regards the use of copper and copper losses.

A bank of 5 - 200 kw. transformers will handle the load for this plant, and will need to have a rating of 2300 / 440 volts, or a voltage ratio of 5.25 to one.

Steam Boilers.

Calculations for size of boilers and their auxiliaries are as follows:-
1. Steam rate as previously computed = 21 pounds per kw. hr. Since the plant is to be of 1000 kw. capacity, then there will need to be --

\[ 1000 \times 21 = 21,000 \text{ lbs. of feed water supplied to the boilers per hour.} \]

This will be - \[ \frac{24 \times 21000}{504000} = 60,500 \text{ gallons of feed water per 24 hour day.} \]

2. An efficiency of boiler, furnace and grates combined will be assumed as = 70 percent for use in the following calculations. (This is given in "Mechanical Engineer's Handbook" and also in Allen & Bursley's "Heat Engine Text", as an average value for good conditions of operation.) Referring to appendix 4 --

\[ E = \text{Heat utilized per pound of dry fuel fired} \]
\[ \text{Heating value of 1 lb. of dry fuel.} \]

Since fuel oil is cheaper per hr. hr. than coal, in the particular locality chosen as a site for this mill, the boiler calculations will be made on the basis of oil as fuel.

Note.
Natural gas is, as a matter of fact the cheaper and cleaner fuel for use in this locality but the supply is limited, especially during the colder months, and hence, it would be necessary to have auxiliary oil handling and oil burning equipment, including the necessary tanks, pumps, etc.)

(a). Properties of Texas and Kansas crude fuel oil.

1. Baume' = 18 degrees 3. Carbon = 85.7 percent.
5. Oxygen = 3.31 percent 6. Flash point = 244 Deg. F.
7. Heating value= 19,240 B.t.u. per pound.

then, \[ E = .70 = \frac{\text{Heat utilized per pound of dry fuel fired}}{19240} \]
\[ \text{or, } X = .70 \times 19240 \]
\[ = 13,468 \text{ B.t.u. per lb.} \]

(Reference - Power Plant Engineering Handbook)

\[ X_2 = \text{Heat necessary to evaporate one pound of water under the given conditions} = H - (t - 32) \text{ B.t.u.} \]

Where \( H = \text{total heat in 1 lb. of steam at 180 lb. pressure.} \)
(at 180 lb. gage - temp. of sat. st. = 373.1 deg. F. - superheat temp. = 560 deg. F. - hence, 186.9 deg. of superheat)

\[ H \text{ for a temp. of 373.1 deg. F. and 180 lbs. gage = 1196.2 B.t.u.} \]
\[ t = \text{temp. of feed water} = 150 \text{ deg. F. (assumed).} \]
then, \( X_2 = 1196.2 - (125 - 32) \)

\[ = 1103.2 \text{ B.t.u. per lb. of water.} \]

then,

\( \text{lbs. water evaporated per lb. of fuel burned} = \frac{X}{X_2} \)

\[ = \frac{13463}{1103.2} = 12.2 \text{ lbs.} \]

Total water to be evaporated per hour \( = 21000 \text{ lbs.} \)

Pounds of fuel oil required per hour \( = \frac{21000}{12.2} \)

\( = 1720 \text{ lbs.} \)

Gallons of fuel oil required per day (24 hours) \( = \frac{1720 \times 24}{7.33} \)

\( = 5232 \text{ gal.} \)

Heat used in evaporating water under the assumed conditions

\( = 21000 (1196.2 - (125 - 32)) \)

\( = 21000 \times 1103.2 \)

\( = 23,167,200 \text{ B.t.u.} \)

The equivalent evaporation from and at 212 degrees F.

\( = \frac{23,167,200}{970.4} \)

\( = 23,873 \text{ lbs. per hour.} \)

The required Boiler Hp. then \( = \frac{23 \times 873}{34 \times 5} \)

\( = 692. \)

Three water tube boilers with 200 H.p. ratings each will carry this load very nicely as it is more economical to operate boilers at a reasonable overload than to operate them at loads less than their ratings. The proposed boilers and their locations are shown on the plan and elevation drawings, of the mill and power plant.

The auxiliaries are an economizer to be located as shown, in the breeching and the superheater to be located above the water tubes, between the tubes and the drums. Since 4 to 5 sq. ft. of economizer surface should be allowed per boiler horse-power.

Economizer surface req. \( = \frac{200}{5} = 40 \text{ sq. ft. per boiler.} \)

A superheater is a very good investment, also, since superheating steam (for a turbine plant) from 100 degrees to 200 degrees F. effects a saving of 1 percent in steam consumption for every 12 degrees of superheat.

(References: Allen & Bursley's "Heat Engines" and Power Plant Engineering Hand Book.)

Note:

Two-300 Hp. boilers or even one 650 Hp. boiler could have been selected to carry the load estimated above, very nice-
ly. The reason for selecting 3 - 200 Hp. boilers is as follows:-
At times it is necessary to repair one boiler (or more, if the battery is large) out of a battery. At such times, with the boilers rated as suggested above, the remaining two boilers may be overloaded sufficiently, without harm to them or to the system, to assume the entire estimated load of the plant (692 Hp.). The third boiler may then be repaired, and brought back into the service without a loss of time, shutting down the plant, or a loss of plant efficiency.)

Smoke Stack.

This is a very important part of the steam power plant, since the operation of the plant depends upon the draft and capacity of the chimney.

(a). Draft.

The draft in a chimney is produced by the difference in weight between the column of gases (hot gases) inside the chimney and a column of gases (cold gases) of the same dimensions outside of the chimney.

The hot gases, being light, are forced up the chimney by the cold gases coming thru the gates. The height of the chimney determines the intensity of the draft, which is measured in inches of water.

The force of the draft in inches of water is

\[ F = 0.192 \, H \, \omega \left( 1 - \frac{T^0}{T'} \right) \]

Where \( T^0 \) = absolute temp. of the gas outside the chimney.
\( T' \) = " " " " " " inside " " " " " .
\( \omega \) = weight of a cubic foot of air at a temp. T

(b). The height of the stack or chimney is determined as follows:-

Each boiler Hp. requires approximately 3 lbs. of oil, (fuel) for this plant.

Weight of air required per lb. of fuel estimated at 50 lbs., or assuming an average efficiency for the stack of about 35 percent (Reference:-- A & B "Heat Engines"), then the actual weight of air passed per hour is

\[ \omega = 378 \, A \sqrt{H} \]  where \( A \) = area of stack in sq. ft. and \( H \) = height of stack above the furnace floor in feet.

Boiler Hp. of stack then = \( \frac{378}{3 \times 50} \, A \sqrt{H} \)

or, \( 692 = \frac{378}{3 \times 50} \, A \sqrt{H} \)

or, choosing Diam. of stack = 6 ft. = 72 inches, then, \( A = 28 \) sq. ft.
Then, \( H = \frac{692}{2.5 \times 28} = \frac{692}{70} = 9.9 \)

If each section of stack is 4 feet high, then there will need to be \( \frac{100}{4} = 25 \) sections for entire stack above the furnace floor.

(c) Referring to item (a) above, and assuming \( T^\circ = 530 \) (for outside temp. = 70 deg. F.) \( w^\circ = .075 \) lbs. and \( T' = 960 \) deg. F.

then, Force of draft in inches of water = \( \frac{192 \times 100 \times .075}{(1 - \frac{530}{960})} = 19.2 \times .075 \times \frac{1}{1 - .55} = 19.2 \times .034 \)

= 0.65 inches of water.

(d) Due to the location of the economizers and the subsequent resistance of draft due to same, it is necessary to use an induced draft system. This is accomplished by placing a blower fan in the smoke connection to the chimney. The force of the draft will then be increased to a probable 1.5 inches of water as compared to the figure shown above (.65 inches.)

(e) Size of blower required, in cubic feet of air per minute, assuming that blower will need to supply 1/2 of the air required to produce a draft = to 0.65 inches of water is determined as follows:

Actual weight of air per hour = \( W_a = 378 \times \sqrt{H} \)

= \( \frac{378 \times 28}{100} \) lb. per minute.

= 1764 lbs. per minute.

Air at 70 deg. F. weighs .075 lb. per cubic foot.

\( \frac{1/2 \times 1764}{.075} = \frac{2366}{2} = 1183 \) cu. ft. per minute.

Fuel Oil Supply Tanks.

(a) Referring to page 36, the fuel oil required per day = 5232 gallons, and the average weight of the oil = 7.88 lbs. per gallon.

For a 15 days supply the tank capacity would need to be approximately \( 15 \times 5200 = 78000 \) gallons.

Using three horizontal steel tanks of the standard type, the capacity per tank would then need to be \( \frac{78000}{3} = 26000 \) gallons.

Twenty-four feet is a good length to choose for one of these tanks as at this length only 3 concrete cradles (assuming storage above ground) are required to support the tanks, 3 feet being the maximum span between supports for this type of tank.
Details of Reinforced Concrete Cradle for 26,000 Gallon Fuel Oil Horizontal Storage Tank.

Note: 3 Tanks Required thus - 3 cradles per tank. Scale \( \frac{1}{4}'' = 1' \)
Volume of tank = \( \frac{26000}{7.5} \) = 3460 cubic feet.

Area = \( \frac{3460}{24} \) = 144 sq. feet.

Then the required diameter of tank = \( \sqrt{\frac{4 \times 144}{3.1416}} \)
= \( \sqrt{183} \)
= 13.5 feet.

(b). Calculations for Concrete Cradles to support tanks.

Total weight of oil per tank = 26000 x 7.83
= 205,000 pounds.

Total weight of tank itself = 16700 pounds.

Weight to be supported by each cradle = \( \frac{16700 + 205000}{3} \)
= 73,900 pounds.

The concrete cradle should encircle at least one-third of the tank's circumference and should conform to the shape of the tank, giving a perfect bearing at all points.

Referring to print No. 16 --

Arc ABC = 1/3 circumference of tank, so that angle AOC = 120 degrees exactly. then, angle OAD = Angle DAB, and s = h = \( \frac{13.5}{2} \) = 6.75 feet. Cos. angle OAD = .866 = a/13.5/2

Therefore chord AC = 2 x .866 x 13.5/2 = 11.7 feet.

or, approximately 11 feet and 3 1/2 inches.

Use 13 feet for width of cradle above ground, and 15 feet for total width of footing beneath the ground. Extend cradle 3 feet and 0 inches below the ground (below frost), and 2 feet and 6 inches to bottom of tank above ground. This will give a total height for cradle (to highest point) above ground of 8 feet and 9 inches approximately.

Treating the cradle as a column the calculations for strength, reinforcing, etc., are made as follows:-

Assuming the length of the top of the cradle to be equal to the chord A C = 11'-3.5" = 140.5 inches and the width (thickness of cradle) to be 8".

Then the area = 8 x 140.5 = 1124 square inches. Total weight
on each cradle = 73,900 pounds. Force in lbs. per sq. in.
= \[\frac{73900}{1124} = 656\] lbs.

Since concrete has a compressive strength of 650 lbs. per sq. inches, theoretically the cradle would not need to be reinforced, but to insure safety against cracking, wind loads and horizontal stresses of other kinds, the cradle should be treated as a column and reinforced as such, as shown on blueprint No. 16, with 3/8 inch vertical rods extending from top and binding at bottom (in footing) spaced 8 inches on centers; and 1/4 inch horizontal rods, spaced 8 inches, tied to the vertical rods at intersections, as shown.

Raw Stock Storage Warehouse.

Referring to page 12, the capacity for the raw stock storage room is to be 2400 tons.

Assuming bales to be 2 ft. x 3 ft. x 4 ft. volume per bale = 24 cubic feet. Average weight per bale = 500 pounds. Total number of bales = \[\frac{2400 \times 2000}{500} = 9600\] bales.

The dimensions of the room will be calculated on basis of piling bales in tiers of 480, the bales lying flat on their 3 feet x 4 feet sides, the 2 foot dimension then being the height of each bale in the tier. Allowing for an 8 ft. aisle thru the room, running the entire length from end wall to end wall, there will be 4800 bales in each 1/2 of the room on each side of the aisle. If the bales are piled in 10 tiers, running the full length of the room, each tier being 12 bales high and 40 bales long, then there will be \[10 \times 12 \times 40 = 4800\] bales in each side of the room or a total of 9600 bales in the entire room. The dimensions of the room will need to be as follows:-

1. Length = \((40 \times 4) + 4 \text{ feet clearance} = 164 \text{ feet.}\)
2. Width = \(2 \times (10 \times 3) + 8 = 68 \text{ feet.}\)
3. Height of ceiling = \((12 \times 2) + 4 \text{ feet clearance for sprinkler system lines, monorail hoist, etc.} = 28 \text{ feet.}\)

As shown on plate number 3, this room should be equipped with a 1-ton monorail hoist, the rail to extend the entire length of the room directly over the 6 ft. aisle, and extending thence into the beater room as shown. The hoist should be equipped with a swivel attachment to facilitate pulling bales from tiers on either side of the aisle and near the walls. The hoist may be used for pulling bales from the tiers and conveying them into the beater room but a 1 - ton stacker of the motor driven platform type should be used for piling the bales in tiers, since the stacker may be pulled around from place to place in the room until all storage space has been filled and may yet be used for piling and unpiling when all space has been occupied except the 8 ft. aisle.

Finish Paper Storage Room.

Referring to page 12, the capacity for the finished paper (in rolls) storage room should be 1200 tons. Since a finished roll of
container board (16 point) 40 in. diam. x 66 inches in length weighs one ton, then the capacity of the storage room should be for 1200 rolls, 40" x 66".

The rolls are stacked in tiers, 5 high with a 2 inch plank between each tier of rolls and the tier above, as shown in the elevation of the mill. Dividing the room into fourths and extending a clear aisle 7 feet wide through the room to each wall from the center of the room, there will be 300 rolls in each 1/4 section of the room. The tiers in each section may be 5 rolls high (17' - 6") and 20 rolls long (66' - 8"). There will then need to be 3 such tiers (3 x 100 = 300 rolls) per section and the total space occupied by rolls in each section will be 17' - 6" x 66' - 8" x 16' - 6" (3 x 66" = 16' x 6"). Allowing for the 7 foot aisles and 4 feet of clearance above the rolls (between rolls and ceiling of room) for operating a 1 1/2 ton traveling crane (as shown on print No. 2) the dimensions of the room will be as follows:

<table>
<thead>
<tr>
<th></th>
<th>Width</th>
<th>Length</th>
<th>Height of ceiling</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>40 feet</td>
<td>140 feet - 4 inches</td>
<td>21 feet - 6 inches</td>
</tr>
</tbody>
</table>

Note.

The question of lighting and heating will not be taken up in this paper other than to mention that the single phase, 110 volt power for lighting is generally purchased from some outside source, due to the fact that it may be necessary to have light in a mill although the power plant and hence the remainder of the mill may not be operating, hence it would not be economical to operate the power unit simply to produce the current necessary for lighting purposes. As regards the heating system, this is generally installed in the form of heating coils built up of pipe (1 1/2 to 2") and situated so as to afford the best results for radiation of heat throughout the room or building.

Building Construction, etc.

(a). The accompanying print, number (17) is a detailed plan of the proposed mill, first and second floors, and also shows the location of all equipment as described throughout the body of this paper. The level of the first floor is taken as four feet above the level of the top of the rail (A.T. & S.F. Ry. side track - see print No. 18 for elevations) to facilitate loading and unloading cars by way of the loading docks.

(b). Water storage tank for sprinkling system.

Required capacity = 40,000 gallons.
Required Height = approx. 100 feet (to give proper pressure in sprinkling system = 40 to 45 lbs. per sq. in.)

Let V = required volume, then size of tank in calculated as follows:

\[ V \text{ required} = \frac{40,000}{7.5} = 5333 \text{ cu. ft.} \]
\[ V = h \times A \text{ where } h = \text{height of tank, and } A = \text{Area of tank. (cross section).} \]

Assume a diameter of 20 feet,

\[ A = \frac{3.14 \times (20)^2}{4} = \frac{314}{4} = 314 \text{ sq. ft.} \]

\[ V = h \times A \text{ or } h = \frac{V}{A} = \frac{5333}{314} = 17 \text{ Feet.} \]

An elevation of the tank is shown on plate number 19. The footings should be of concrete and of the proper size to support the tank and supporting tower. The design shown is standard for this type of tank, the tower being built of steel angle irons and the tank being of sheet metal construction. Such a tank must also be provided with steam coils to maintain a water temperature above freezing during the winter months.

(c). See print No. 18.

The "flat slab" type of reinforced concrete floor is extensively used at the present time for beater rooms - where the beaters are located on the second floor of the mill as shown on print number 17 (plans of first and second floors). Beater and Jordan room floors are generally designed to sustain a live load of about five hundred pounds per square foot.

Using a span of 25 feet between columns for the 50 foot way of the beater chest and pump room (beater room basement) and a span of 23 feet between columns for the 69 foot way of the building (ref. to print No. 18).

The approximate axial load on each of the two columns shown (figure A) is calculated as follows:

Axial Load per column = (25x23x500) plus (25x23) x (187 plus 5) (where 187 = wt. of slab per sq. ft.) 5 = wt. of reinforcing bars, etc. = 287,500 plus 110,200 = 397,700 pounds total.

Referring to Appendix 4 - a 25 inch round column, 21 inch core diameter, reinforced with, 10 - one inch round vertical bars and 7/16 inch round spiral reinforcing rod with a pitch of 2 1/4 inches, will sustain an axial load of 408 thousand pounds. This column will therefore carry the load calculated above = approximately 397,700 pounds. The ratio of unsupported length of column to its diameter should not be over 15 -- or, \( \frac{12 \times 15}{21} = 9 \) approximately, therefore length is within the required limit.

Referring to Appendix 5 for a span of 25 feet the dimensions of the slab and column head parts are as follows:

\[ C = 10' - 0'' \quad T = \text{thickness of slab} = 14 \text{ inches.} \]
\[ D = 63 \text{ inches.} \quad H = 20 \text{ inches.} \]

An elevation of the column, head, and flat slab floor is shown in figure "B" - print No. 18.
SECTION E-E THRU BEATER
AND JORDAN ROOMS - 1st & 2nd FLOORS.
Sub $31' x 31'$
Referring to Appendix No. 6 and Figure "C" of print No. 13 the dimensions of the footings for the columns are as follows:

For an assumed soil value of 4000 lb. per sq. in. -

L = 10 ft. = 6 inches (length and width of base)
Column Load = 405,000 lbs.
h = 1 ft. = 4 inches.
b = 3 ft. = 3 inches.

Reinforcing rods = 13 = 5/8 inch round rods each way = 3 inches up from base of concrete footing to center of rods.

(d). Jordan Room.

The maximum span for each of the two columns supporting the flat slab floor of this room = 23 feet and the minimum span = 20 feet (see print No. 13). The approximate axial load on each column

\[ \begin{align*}
&= (23 \times 20 \times 500) \text{ plus } (23 \times 20)(187 \text{ plus } 5) \\
&= 230,000 \text{ plus } 83,000 \\
&= 313,000 \text{ pounds total.}
\end{align*} \]

Referring to "Useful Data" h.b. by Corrugated Bar Company, page 122, a 20 inch diameter (round) column with a core diameter of 16 inches, reinforced with 8 - one inch round bar verticals and 7/16 inch round spiral reinforcing - 1 7/8 inch pitch will sustain an axial load of 318,000 pounds. The same size footing is shown for this column as for the 25 inch columns in the beater room basement (see print No. 13).

The floor slab should be same as for the beater room = 14 inches, since maximum span in this room is 23 feet (as per minimum span in beater room).

(e). Warehouses, Machine room and Power plant Building.

1. Finished rolls storage building.

A solid concrete slab floor will be used for this building, the slab to be supported by beams and columns (short) as shown on print No. 19.

Area under one tier of rolls = \(3.33 \times 5.5 = 18.5\) sq. feet.
Total weight of rolls (total of 5) = \(5 \times 2000\) lb. = 10,000 lbs.
Pounds per sq. ft. = \(\frac{10,000}{18.5} = 540\) lbs.

A live load value of 600 lbs. per sq. ft. will be used in selecting a floor slab for this building.

From Appendix No. 7 -- for a span of 10 feet and a safe load of 621 lbs. per sq. ft., the slab thickness should be 8 1/2 inches.

2. Raw stock storage buildings.

The area under each tier of 12 bales = \(3 \times 4 = 12\) sq. feet.
Weight of each tier of bales = \(12 \times 500 = 6000\) pounds. Load in lbs. per sq. ft. on floor = \(\frac{6000}{12} = 500\) lbs. per sq. ft. and the slab thickness will be 8 1/2 inches, same as for the roll storage building.
3. The machine room and power plant building floors should also be of 8 1/2 inch slab construction, properly reinforced. (see Appendix No. 7)

(f). The roof construction is shown throughout as supported by steel trusses of the compound Fink type - with a fire proof covering of sheet steel and gypsum. Ventilators are shown over the machine and boiler rooms, to facilitate the disposal of steam and gases. (see print No.19).

(g). The oil burning system may be arranged as shown on print No. 19 -- the main equipment consisting of a steam pump, blower, steam traps, oil heater, pressure regulator, tank heater, and oil burners of the air injector type.

(h). Smoke Stack.

The stack may be erected as shown (print No.19) on a reinforced concrete base. The bottom section of the stack should be equipped with a steel flanged collar, the flange resting on the concrete foundation. This flange should be bolted to the concrete by means of bolts of sufficient size to stand the stresses due to wind pressure on the stack, etc. These foundation bolts should be set in the concrete to a sufficient depth to prevent being pulled out by the stresses referred to above. The concrete foundation or footing should be reinforced as per a footing for a column of same weight as the stack, and should be of ample proportions to resist being turned over or twisted in the ground by any forces due to stack loads, wind pressure, etc.

Some of the forces on such a stack are as follows:

Wind pressure .............................................30 lbs. per sq. ft.
Total wind pressure on stack..........................50x6x100 = 15,000 lbs.

If this pressure is considered as acting at a point half way up the stack -- Then the turning moment at the bottom of the stack, or the force tending to pull the bolts out of the foundation would be 50 x 15,000 = 900,000 lbs.

(i). The short columns (cross, or tee beams to support the floor slab not shown) supporting the first floors of the warehouses, machine room and boiler room, etc., are as shown on plate No. 19.

The span of the slabs in all cases = approximately 10 feet as there is no basement under the mill and hence the space occupied by columns is of no material importance.

Total load per beam including weight of beam = $\sqrt{\frac{150}{750} \times \sqrt{\frac{150}{750}} \times 600} = 49 \times 600 = 29,400$ lbs. (Area of slab per beam = $\sqrt{\frac{150}{750} \times \sqrt{\frac{150}{750}}} =$ approximately 49 sq. ft.)
Weight per foot = \( \frac{29400}{10} = 2940 \) lbs.

Refer to "Useful Data", page 105, as shown:

A tee beam with a span of 10 feet will sustain a safe load of 3095 pounds if dimensions and reinforcement are as follows:
\[ b = 12 \text{ inches}, \]
\[ h = \text{depth of beam} = 14 \text{ inches}. \]

Reinforcing = \[ 2 = \frac{3}{4}'' \text{ round bars (straight)} \]
\[ 2 = \frac{3}{4}'' \text{ " (trussed) } \]

Also, the axial per short column (6 to 10 ft.) = \( 10 \times 10 \times 600 = 60,000 \) pounds. From "Useful data" page 115, a 14" column (round) reinforced with \( 4 = \frac{3}{4}'' \) vertical bars, and \( 1/4'' \) spiral rods will sustain an axial load of 62,000 pounds, if made of 1:2:4 concrete. The footings may be of standard square design as shown on print No. 19.

**Conclusion**

As noted on plate number 19, a combination brick and reinforced concrete construction is suggested for the walls of all buildings, the concrete to form the beams and pilasters and the brick to be used as a fill in material. This provides a very good wall for a paper mill since there is generally an excess of vibration set up inside the mill due to the use of very heavy machinery. This, together with the storage of heavy rolls and bales, also explains the use of the large beams, columns and floor slabs throughout the mill.

Other details, for which little or no explanation has been offered are as shown on plate number 17.
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APPENDIX I

Raw Materials

Raw Materials from which a sheet of standard .016 caliper container board are made:

Standard .016 caliper, 85 pound test container board is composed of waste papers and kraft (wood pulp) or kraft papers in the following proportions per ton of board made, approximately:

1. 300 pounds of kraft or wood pulp.
2. 1700 pounds of waste papers plus (chemicals)

Total. 2000 pounds = One Ton.

Then the actual percent of kraft in the finished board is, neglecting the chemicals added to the mixture of stock for waterproofing, coloring and size setting purposes,

\[
\frac{300}{2000} = 0.15 \text{ or } 15\% \text{ by weight.}
\]

Note: The chemicals referred to above are coloring powders, rosin size and alum. These substances are added to the paper stock while the stock is being passed through the beating process and the amounts added depend upon the results desired. This is entirely paper chemistry and will not be taken up in detail in this problem -- which is the design of the mill to produce a board and not a chemical treatise.

Hence a ton of finished board is composed of 15% kraft and 85% waste papers plus chemicals, or probably 15% kraft, 82% waste papers and 3% chemicals.

The actual weight of materials required to produce a ton of finished board, however, is more than 2000 pounds. This is due to the shrinkage, the factor by the way, to which all paper mill operators devote a lot of attention. Shrinkage might be defined simply, as that part or percent of the materials furnished to the beaters which does not enter into the finished board, or, in fact, is lost in the process of producing the finished board. The value of shrinkage varies and is dependent on a good many factors. A good average value, however, might be taken as about 8%. In other words the materials actually supplied from which to produce the finished board would be 1.08 x 2000 pounds, or

1. 0.15 x 2160 = 324 pounds of kraft.
2. 0.82 x 2160 = 1771.2 " waste papers.
3. 0.03 x 2160 = 64.80 " chemicals.

Total. 2160.00 " materials.

A word should be also offered at this point concerning the moisture content of the finished board. Some reason should be offered, probably, for not mentioning this item in calculating the weights of materials in the finished board. An explanation
APPENDIX I (Continued).

might be offered as follows:—

Waste papers, together with the kraft and chemicals introduced into the process, contain, when in their raw form, about the same percentage of moisture (water) as a finished sheet of container board, namely, about 6 to 8 per cent by weight. Therefore, since water or moisture is not added (does not remain in the sheet) in the process it should not be included in the calculated weight of materials required to produce the finished board.

APPENDIX II.

(From Catalog No. 149, The American Well Works Company, Aurora Illinois).

To Determine Capacity, Speed and Head of Centrifugal Pumps.

Assume that the quantity of water lifted by a pump running at N, r.p.m. is Q, g.p.m. and total head is H, feet requiring P, H.P. delivered to pump to operate.

Further, that the same pump running at N, revolutions, pumps Q2 g.p.m. against total head of H2 feet requiring P2 H.P. delivered to pump to operate.

(In order to simplify the equations, all constants will be eliminated, as the results obtained will be near enough for most practical purposes).

1. \( \frac{Q_1}{Q_2} = \frac{N_1}{N_2} = \sqrt{\frac{H_1}{H_2}} \)

2. \( \frac{P_1}{P_2} = \left(\frac{H}{H_1}\right)^3 \)

APPENDIX III.


The amount of heat conducted (transmitted) through a material in a given time is directly proportional to the difference in temperature between the two parallel sides of the substance and inversely proportional to the thickness, or —

\[ H = \frac{c}{b} (t_1 - t_2) \]

where c = coefficient of transmission; b = thickness of material in inches; t1 and t2 = respective temperatures.

From table No. 26 -- The Coefficient of transmission for wrought iron = 0.00089.

From table No. 29 -- for wrought iron steam pipe.
### APPENDIX III. (Continued)

<table>
<thead>
<tr>
<th>Diameter in inches</th>
<th>Thks. in inches</th>
<th>Cir. in inches</th>
<th>Ext. Areas sq.in.</th>
<th>Int. Areas sq.in.</th>
<th>Length of pipe per sq. ft.of Ext. surface in feet</th>
<th>Ft.of pipe containing 1 cu. ft.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Int.</td>
<td>Ext.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>.315</td>
<td>.134</td>
<td>4.131</td>
<td>1.358</td>
<td>.8609</td>
<td>2.904</td>
</tr>
<tr>
<td>1/4</td>
<td>1.900</td>
<td>.145</td>
<td>5.969</td>
<td>2.835</td>
<td>2.038</td>
<td>2.010</td>
</tr>
<tr>
<td>2</td>
<td>2.375</td>
<td>.154</td>
<td>7.461</td>
<td>4.430</td>
<td>3.356</td>
<td>1.608</td>
</tr>
<tr>
<td>2 1/8</td>
<td>2.875</td>
<td>.204</td>
<td>9.032</td>
<td>6.492</td>
<td>4.780</td>
<td>1.328</td>
</tr>
</tbody>
</table>

### APPENDIX IV.


Spiral Columns (Round form)
Safe Axial Loads in thousands of pounds.
New York City Building Code requirements.
Ratio of Length of Column to its diameter limited to 15.

| Column Diam. | Core Diam. | Round Bar Diam. | Verticale 1:2:4 Concrete f_p = 600 lb per sq. in. |
|--------------|------------|-----------------|-----------------------------------------------|-----------------------------------------------|
| inches       | inches     | No. Size        | 5/16"φ-2"P | 7/16"φ-2½"P | 1/2"φ-2"P |
| 8            | 3/4        | 302             | 378          | 464          |
| 10           | 7/8        | 319             | 395          | 481          |
| 10           | 1          | 332             | 403          | 494          |
| 13           | 1 1/8      | 349             | 425          | 511          |

### APPENDIX V.


Flat Slab Floors. Standard Corr. - Plate two way system.
Concrete sizes and weight of reinforcement per sq.ft.for Square Interior Panels. f_p = 18,000 f_o = 700.

<table>
<thead>
<tr>
<th>L ft.</th>
<th>C ft.-in.</th>
<th>D in.</th>
<th>T in.</th>
<th>H in.</th>
<th>Wt.of reinforcement lb. per sq.ft.</th>
<th>Wt.of reinforcement lb. per sq.ft.</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>8 0</td>
<td>54</td>
<td>11</td>
<td>16</td>
<td>148</td>
<td>379</td>
</tr>
<tr>
<td>23</td>
<td>9 -3</td>
<td>62</td>
<td>12½</td>
<td>18½</td>
<td>163</td>
<td>422</td>
</tr>
<tr>
<td>24</td>
<td>9 -9</td>
<td>65</td>
<td>13</td>
<td>19</td>
<td>175</td>
<td>453</td>
</tr>
<tr>
<td>25</td>
<td>10 -0</td>
<td>68</td>
<td>14</td>
<td>20</td>
<td>187</td>
<td>476</td>
</tr>
</tbody>
</table>
### APPENDIX VI.

**Column Footings.**

Reference - ("Useful Data" - by Corrugated Bar Company, Inc., Page 140)

Square column footings

Unit stresses - $f_s = 16,000$

$ f_c = 650$

<table>
<thead>
<tr>
<th>L (ft. in.)</th>
<th>Soil value</th>
<th>Column Load (lb. per sq. ft.)</th>
<th>Min. Col. Diameter (inches)</th>
<th>h (ft. in.)</th>
<th>b (ft. in.)</th>
<th>Rein. bars each way</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.6</td>
<td>4000</td>
<td>405</td>
<td>23</td>
<td>1</td>
<td>4</td>
<td>3 8 18 5/8</td>
</tr>
</tbody>
</table>

### APPENDIX VII.

Reference - ("Useful Data" - by Corrugated Bar Company, Inc., Page 66)

Solid concrete slabs - Continuous over supports.

Bending moment = $1/12 \text{w} \times 1 \times 1$.

Unit stresses - $f_s = 18,000$

$ f_c = 700$

<table>
<thead>
<tr>
<th>Thickness of slab (inches)</th>
<th>Weight of slab per sq. ft. (pounds)</th>
<th>Round bars Size spec.</th>
<th>Span of slab in ft.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>inches inches</td>
<td>9 1/2 10 10 1/2</td>
</tr>
<tr>
<td>8</td>
<td>100</td>
<td>3/4 9</td>
<td>607 538 473</td>
</tr>
<tr>
<td>8 1/2</td>
<td>106</td>
<td>3/4 8 1/2</td>
<td>-- 621 554</td>
</tr>
<tr>
<td>9</td>
<td>112</td>
<td>3/4 8</td>
<td>-- -- 637</td>
</tr>
</tbody>
</table>