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The Pressability of Once Dried Pulps vs Never Dried Pulps

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THE PRESSABILITY OF ONCE DRIED PULPS
VS NEVER DRIED PULPS

BY

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ABSTRACT

A study was made on the dynamic press simulator to determine the pressability differences of once dried pulps and never dried pulps. As water is removed in the drying process, nearly all of the water-to-cellulose bonds are replaced by cellulose-to-cellulose bonds. Rewetting the dry pulp reestablishes only part of the water-to-cellulose bonds. Therefore, at the same moisture content the once dried pulp holds its water 'looser' than the never dried pulp. The results prove that previously dried pulps reach higher consistencies in the press section than pulps that have never been dried. The results also indicate that the dynamic press simulator used for this study should be perfected prior to continued study.

KEYWORDS: Wet Pressing, Simulation, Water Removal

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INTRODUCTION

As the price for energy continues its upward trend, energy expenses constitute an increasing proportion of the total paper production cost. Since approximately 80 percent of the energy consumed on the paper machine is used to evaporate water from the wet mat, increasing water removal prior to evaporative drying is an inviting route to obtain energy savings (1).

In addition to increasing the energy savings in the dryer section, improved wet pressing can lead to higher machine speeds and increased production with the same energy consumption. Increasing the solids content by one absolute percent in the press section reduces the energy consumption in the drying section by approximately three percent (2).

Much of the research into achieving greater water removal in the wet press sections has dealt primarily with equipment development (1). This has resulted in the introduction of extended-nip presses, grooved rolls, drilled rolls, double-felted presses, and improved fabrics. Little work has been done concerning the fiber web and its characteristics and how these parameters behave in press section dewatering. A better understanding of fiber and furnish variables is needed to optimize water removal by wet pressing.

Since previously dried pulps are frequently used in the manufacture of paper, the effects of pulp drying on wet press-

ability provide an important area to study.

THEORETICAL DISCUSSION

Adsorbtion of Water

Cellulose fibers take up water by true adsorbtion, indicating that no compounds are formed between cellulose and water. Water may be held in the cellulose fiber structure as colloidal or bound water, as capillary water, or as imbibed water (3).

It has been shown (4) that the swelling of cellulose in water is essentially intermicellar, which means the water is imbibed for the most part into the amorphous regions of the fiber without alteration of spacings in the crystalline regions. Relatively large increases in dimensions are involved in this swelling, and intermolecular spacings in the amorphous areas are very greatly increased. With increasing proportions of imbibed water, segments of the molecular chains are further freed to come under the influence of the thermal forces, resulting probably in enhanced power of immobilizing more water into the system.

The hydroxyl groups of the cellulose surface form hydrogen bonds which bind the water to the fibers (5). The molecules in the first layer of water attached to the cellulose are so orientated and tightly packed that the density of the water appears to be about 2.5 g/cm^3. The hydroxyl groups in this first layer attract a second layer of water molecules. This layer is less orderly and, thus, less strongly bound and less dense. Each layer then attracts a subsequent layer which is less orderly than the previous layer. The last layer imperceptibly merges into the surrounding water. At room temperature about seven layers of

water are adsorbed onto the cellulose.

Because of its great attraction to the cellulose surfaces, the water enters the crevices of the fibers by a kind of wedging action. This may cause additional splits or separations in the structure which then adsorb more water and cause additional swelling.

Removal of Water

As water is removed by deswelling the cellulose, the molecular segments are brought closer together. There exists the possibility of chemical bonding between carboxyl and hydroxyl groups to yield cross linkages.

Figure 1 (5) shows a greatly enlarged, highly diagrammatic picture of two adjacent cellulose surfaces, one on a microfibril. A film of water exists between them which has a mensicus near the tip of the fibril. The forces pulling the fibril against the surface involve hydrogen bonding and are ultimately caused by the polar attraction of water molecules for each other and for the hydroxyl groups covering the cellulose surfaces. The mutual attraction of the highly polar water molecules supplies both the tensile force along the surface of the mensicus and also the enormous liquid tension in the water remaining between the cellulose surfaces when they come close together.

During the process of drying, when the radius of the water meniscus is very small, an attractive force is exerted between adjacent surfaces equal to the tensile strength of water itself--about two metric tons per square centimeter. This greatly reinforces the tension between the surfaces of fibrous elements that

initially were brought to the point of near contact through the action of the surface tension of water alone. These forces are thus able to take effect and align the elements and additional hydroxyl groups from the water on closely adjacent cellulose surfaces. As the water departs, the meniscus becomes smaller and smaller whereby the primary hydroxyl groups of the cellulose surfaces ultimately link together by means of hydrogen bonds.

Drying and Rewetting

It has been discussed (6) that as wood is pulped the middle lamella dissolves and the fibers separate from each other and are swollen. Material is also dissolved from the matrix which embeds the fibrils within the cell wall. The fibrils then have more mobility in this loosened cell wall structure and move outward under the pressure produced by swelling. Their angular orientation relative to the fiber axis is temporarily changed. Bonds between the chains of cellulose, hemicellulose, and lignin are broken.

As the fiber dries and contracts, the fibrils position themselves closer to the central fiber axis than in the original arrangement, in spaces left by the dissolution of hemicelluloses and lignin. Thus, the fibrils form a smaller angle with the fiber axis, new bonds are formed, and the internal stresses are distributed differently from those in the original fiber. Simultaneously, the thickness of the cell wall decreases, and the packing density of the wall material increases.

When the cellulose is dried, nearly all of the water-to-cellulose bonds are replaced by cellulose-to-cellulose bonds (3). Wetting a dry fiber by immersing it in water or in any polar li-

quid that serves to loosen the bonds between the elements allows the fiber to swell (5). The forceful penetration of liquid into the hydrophilic surfaces between splits in the structure puts strains on the adjacent hydrogen bonds that link the surfaces together, engages some of them, extends the splits, and so enables the fiber to swell more readily. Therefore, water-to-cellulose bonds are reestablished, but part of the previously established cellulose-to-cellulose bonds remain, thus reducing sorbed water. Hence, wood pulp which has never been dried has a higher moisture content at equilibrium than the same pulp which has been dried and rewetted.

The following adverse changes occur to fibers when they have been dried and rewetted (5):

1. Many of the external fibrils are lost, which causes a reduction in the cohesiveness of the fibers.
2. The structure of the fiber is more tightly bound, resulting in surfaces that are more difficult to fibrillate.
3. The more tightly bound and denser structure makes the fibers more difficult to fibrillate internally and makes them more springy which, together with a reduction of external fibrillation which reduces surface tension effects, causes the resulting sheet to be more bulky.
4. The original fibers have an increased stiffness which makes them prone to shortening as they are refined.

The effects of drying do not become very appreciable until the solids content reaches about 75 percent. Beyond that, the properties commence to change rapidly. The method of drying also

has a considerable influence. The effect on the initial properties becomes progressively more pronounced if the pulp is freeze dried, air dried, vacuum machine dried, conventially machine dried in the open atmosphere, or oven dried.

Effects of Drying on Swelling

As reported by Lyne and Gallay (4), there is a very significant effect of drying on the degree of swelling of the fibers. Jayme measured the effect of drying on the swelling of unbleached sulfite pulp which had not previously been allowed to dry. The swelling determinations were carried out by the centrifuge method, and the results are expressed as the percentage weight of water taken up on the weight of dry fiber.

The degree of swelling of the original pulp with 30.2 percent solids was 159.1 percent. After air drying to 91.6 percent solids, the degree of swelling was reduced to 107.3 percent. After drying for six hours at 70^{o} C to 98.6 percent solids, the degree of swelling was further reduced to 98.7 percent. These results show an irreversible hardening of 32.6 percent and 37.9 percent of the swelling value for the original pulp. This irreversibility was slightly reduced after an hour of soaking at 20^{o} C.

Robertson and Mason produced comparable results by using a permeability method for the measurement of swelling.

Effects of Drying on Strength

Lyne and Gallay (4) studied the effect of pulp drying on paper strength. Wet sulphite pulp in lap form was disintegrated by hand and spread out to air dry. Portions of the pulp were made into handsheets after intervals of drying. Moisture determina-

tions were carried out on portions of each sample. The solids content of the pulps ranged from 30 to 90 percent, and 100 percent solids was obtained by oven-drying a further sample.

Burst, tensile, fold, and tear tests were performed. The results showed large strength losses for burst, tensile, and fold. Up to 73 percent of the strength of the original wet pulp was lost. The tear strength first increased slightly and then decreased sharply. The large decrease in tear in thoroughly dried pulps results from an embrittlement of the fiber and an excessive slippage resulting from lack of bonding.

Compressibility

Wahlstrom's (7) qualitative model of pressing seems to describe water removal well. Of his eight terms used, three are sheet-related (compressibility, flow resistance in the structure, and flow resistance out of the cell wall), and five are mainly external (felt flow resistance, uniformity of pressure application, and three rewetting terms). The first of these eight terms applies to redistribution of water between paper and felt in the nip without access to additional water.

The fiber wall can hold 1.0 to 4.0 kg of water per kg of fiber. Because of the small pore size, this water is the most difficult to remove and is, therefore, the key obstacle to water removal by pressing. The average pore size in the fiber wall is in the order of 10^{-6}. The water retention value (WRV) defines the water held by the fiber wall and relates directly to dryness out of a press section for pressure-controlled conditions.

Because of the water in the cell wall, most of the resistance

to pressing is flow-related. The smaller capillaries in the cell wall require longer time for water removal than those between fibers.

The flow resistance or resistivity, an important characteristic of wet fiber mats, is defined from Darcy's Law

$$Q = \frac{\Delta PA}{\mu R} \quad \text{or} \quad R = \frac{\Delta PA}{Q\mu} \qquad (1)$$

where

Q = flow rate through the mat

ΔP = hydrostatic pressure drop across the wet mat

A = effective area of the mat exposed to flow

μ = viscosity of liquid

EXPERIMENTAL PROCEDURE

Equipment

To simulate a physical event such as pressing, a thorough knowledge of the different parameters is needed. When the sheet passes the press nip, it is exposed to a pressure pulse. Definitions of the different parameters such as maximum specific nip pressure, average specific nip pressure, and press time are shown in Figure 2 (8).

One of the most important parameters is the press impulse

$$\text{press impulse (P)} = \int^{T} p(t)\,dt \qquad (2)$$

where T is the press time and p(t) is the specific nip pressure at time t.

Other parameters are also related to the press impulse

press impulse = (specific pressure) X (press time) (3)

press impulse = (linear nip load) / velocity (4)

The pressure distribution in the machine direction is deter-

mined by the nip width. A short nip width gives a narrow pressure distribution (a high specific pressure and a short press time).

It is the purpose of this experiment to differentiate between the pressability of once dried pulp and never dried pulp. This study will be carried out on an instrument called a dynamic press simulator (Figure 3).

The KMW dynamic press simulator was originally developed by Carl Zotterman and Douglas Wahren (8, 9, 10). This simulator differs from the plane presses in that it uses a simple drop mechanism rather than hydraulic or mechanical loading. This gives cheaper construction, a rapid unload time, and enables short dwell times to be readily attained.

The paper sample is pressed in a nip consisting of a hammer and anvil. The anvil is composed of a 3.5 inch diameter piece of steel which is made to cover a force transducer. The force transducer provides a pressure pulse signal to a storage oscilloscope or similar device. The shape of the pressure pulse given is in good agreement with measurements performed in actual press nips A 3.5 inch diameter piece of hard rubber is placed on top of the steel anvil. This rubber piece is 0.75 inches thick.

The hammer consists of a steel plate which travels on two hard-cased posts with bushings attached to the plate. A rubber disc, similar to that for the anvil, is attached to the bottom of the hammer. Weights in varying amounts can be attached to the top of the hammer.

The hammer is raised to the desired drop height by a cable and a winch. The weights are released by a quick release mechanism

which is attached to the end of the cable.

The weight strikes the pedastal but once, for spring loaded catches on either side of the press prevent the weight from falling back onto the felt and paper after the initial rebound. This provides a much better simulation of the expansion region of a nip than can be achieved with hydraulic or mechanical loading. The rapid rebound permits nip residence times as low as 2 ms to be studied.

A range of pressing conditions can be obtained by altering the drop height (h), the mass (m), the area of the base plate, and the spring constant (k) of the system. Theoretically, the pressure pulse is described by

$$\text{average nip pressure, } \bar{p} \propto \sqrt{kmh} \tag{5}$$

$$\text{nip residence time, } t \propto \sqrt{m/k} \tag{6}$$

The peak pressure can be varied at will, either by increasing the height of the drop or by adding weights to the carriage. The nip residence time can be varied by changing the rubber pad attached to the force transducer.

The press simulator effectively covers an operating range of 300 to 2,000 pli linear nip load and 600 to 15,000 fpm machine speed.

There is, however, a major difference between the drop-weight simulation and an actual press nip. In a press nip the caliper is forced to be symmetrical around the point of minimum clearance between the press rolls, and the pressure is assymetrical owing to the viscoelastic response of the mat. For the simulator the pressure pulse is symmetrical about the time of the peak pressure, and

the caliper is assymetrical.

Stock Preparation

Three types of pulp were used for this experiment, these being S. D. Warren unbleached kraft, S. D. Warren bleached kraft, and Menasha unbleached NSSC. Each of these pulps were obtained in the unbeaten, never dried state. To assure that the once dried pulps were dried to the same degree, part of each pulp type was dried overnight in the oven.

Each of the six pulp groups was refined in a Valley beater following Tappi standard procedure to freeness levels of 500, 400, and 300 CSF.

Test Sample Preparation

Handsheets were made on the British handsheet mold at a basis weight of 150 g/m^2. Fifteen handsheets were made at each freeness level for each of the six pulp groups. This number allowed for three presses at each of four press weights with three spare handsheets remaining. The four weights will be ten, 20, 30, and 40 pounds. The calculations of pressure impulses for these weights are presented in the Appendix.

The handsheets were couched from the forming wire onto a blotter. The blotter and handsheet were then placed between two more blotters and rolled to a point near the desired consistency of 30 percent. After removal from the blotters, each handsheet was 'stamped' with a round die, 3.5 inches in diameter. The resultant handsheets, now 3.5 inches in diameter, were placed in Ziploc plastic bags for storage. A small Ziploc plastic bag was weighed for each handsheet. After pressing, each handsheet will be put in a

separate bag.

Felt Preparation

Circles 3.5 inches in diameter were cut from a used piece of felt from a papermachine press section for the dynamic press simulator. The felts were dried overnight in an oven and weighed while oven dry. New weights of each felt piece were calculated for the required wet to dry ratio of 1.4 / 1 (28.6 percent moisture). All of the felts were then conditioned to the appropriate moisture and stored in a large Ziploc plastic bag.

Pressing Procedure

For pressing the handsheets, the following sequence must be carried out:

1. Two felts and one handsheet are removed from their respective plastic bags. Each of these must be adjusted, by weight, to their desired moisture content prior to pressing. To adjust the moistures either water is sprayed on the felt or web or water is blotted out of the felt or web.

2. The web is placed between the two felts; the whole sandwich is centered on the anvil of the simulator.

3. The hammer containing the proper weight is dropped on the sample from the desired height (2 feet for this experiment). The rebound height for each weight is to be recorded.

4. The handsheet is immediately sealed in a preweighed Ziploc plastic bag. The hammer and weight are raised to the proper height for the next handsheet.

Consistency Calculations

Each handsheet was weighed with its respective Ziploc plastic

bag. The weight of the individual handsheets can then be calculated since the plastic bags were previously weighed. Knowing the new weight of the handsheets enables the calculation of the consistency after pressing. Finally the three handsheet consistencies at each freeness level and weight level were averaged together.

RESULTS

All handsheets were at 30 percent consistency prior to pressing. Following the pressing procedure new consistencies were calculated. These results are presented in both tables and graphs as follows.

S. D. WARREN UNBLEACHED KRAFT

	NEVER DRIED			ONCE DRIED		
	500	400	300	500	400	300
10 lbs.	36.41	34.25	32.95	38.40	36.98	36.14
20 lbs.	37.93	35.25	33.93	41.09	41.38	37.14
30 lbs.	38.19	35.92	33.79	38.51	39.80	35.60
40 lbs.	37.24	36.24	34.20	40.42	41.76	34.02

TABLE 1. CONSISTENCY AFTER PRESSING

S. D. WARREN BLEACHED KRAFT

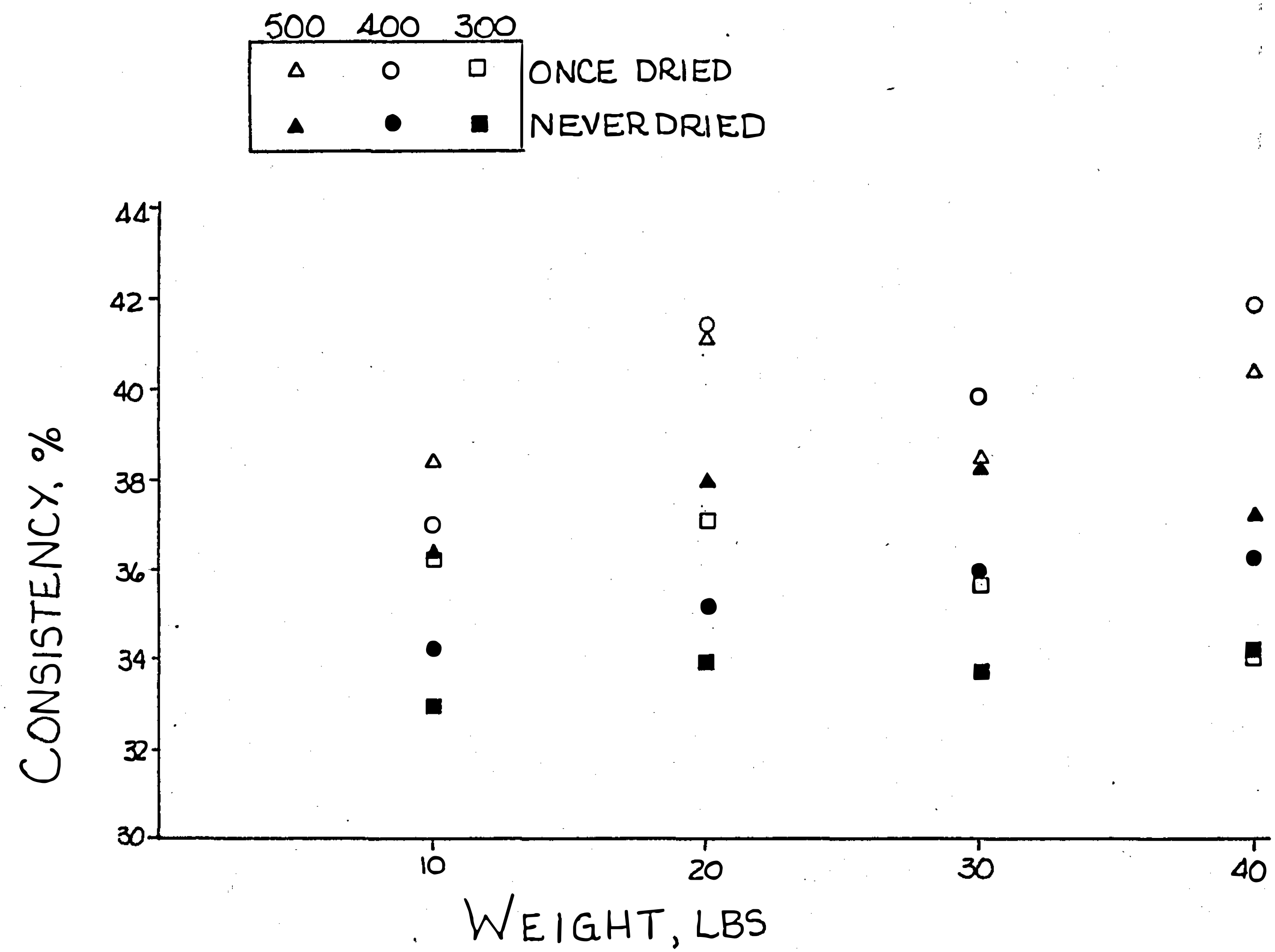
	NEVER DRIED			ONCE DRIED		
	500	400	300	500	400	300
10 lbs.	36.72	33.72	31.54	38.24	37.10	33.76
20 lbs.	37.97	34.61	33.53	41.65	39.92	35.01
30 lbs.	39.33	35.93	35.07	42.06	40.34	37.93
40 lbs.	39.30	37.51	35.42	44.19	41.34	37.81

TABLE 2. CONSISTENCIES AFTER PRESSING

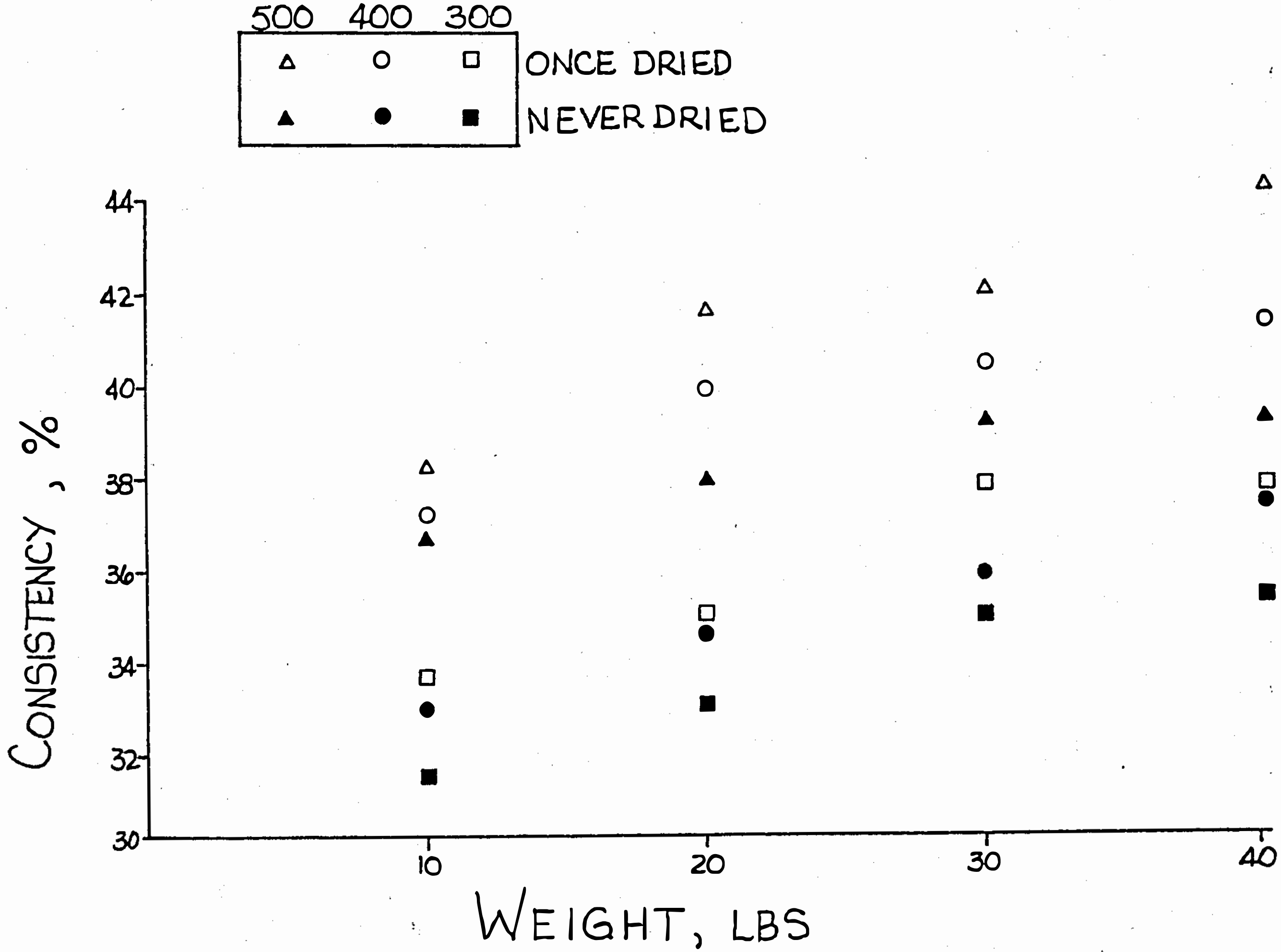
MENASHA UNBLEACHED NSSC

	NEVER DRIED			ONCE DRIED		
	500	400	300	500	400	300
10 lbs.	36.34	35.78	33.86	37.51	39.15	36.63
20 lbs.	37.81	34.81	35.59	37.44	37.60	33.42
30 lbs.	33.59	32.91	34.58	39.36	35.54	35.93
40 lbs.	37.26	34.86	33.72	33.41	36.30	36.64

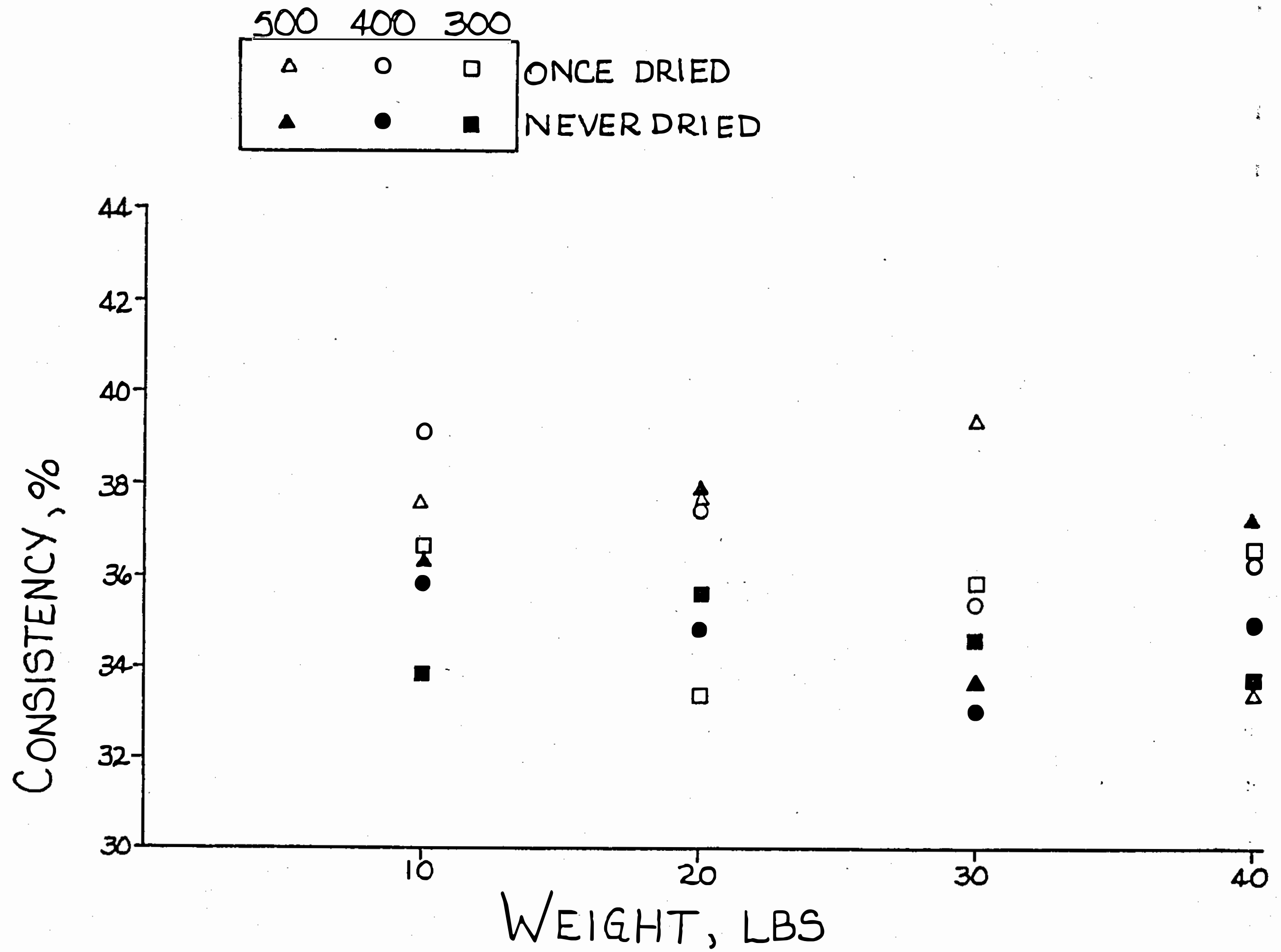
TABLE 3. CONSISTENCIES AFTER PRESSING



GRAPH 1. THE EFFECT OF PRESSING ON UNBL. KRAFT



GRAPH 2. THE EFFECT OF PRESSING ON BL. KRAFT



GRAPH 3. THE EFFECT OF PRESSING ON UNBL. NSSC

DISCUSSION OF RESULTS

The preceeding tables and graphs exhibit some noticeable trends. One such trend is with the relationship between freeness and consistency out of the dynamic press simulator. The results show that the higher freeness level pulps came out of the press at higher consistencies than the lower freeness level pulps.

The freeness test gives an arbitrary measure of the rate at which water may be drained from pulps. Therefore, the higher the freeness level, the faster the water will drain from the pulp. This analogy holds true when considering water removal by means of pressing rather than drainage. Under action of a press such as the dynamic press simulator more water is removed from the pulp sample with the higher freeness level. Therefore, these pulps leave the press at a higher consistency level than the pulps with the lower freeness level.

The results strongly indicate that once dried pulps can be pressed to higher consistencies than pulps that have never been dried. The fibers of the once dried pulps were subjected to changes unseen by the never dried pulps. As water was removed in the drying process, nearly all of the water-to-cellulose bonds were replaced by cellulose-to-cellulose bonds. Wetting the dry fibers by immersion in water reestablished only part of the water-to-cellulose bonds. Therefore, at equilibrium, the once dried pulp has a lower moisture content than the same pulp that has never been dried.

When both the once dried pulp and the never dried pulp are

adjusted to the same moisture content, the once dried pulp holds its water more 'loosely' since only some of the water is held by the water-to-cellulose bonds. The never dried pulp with its larger number of water-to-cellulose bonds holds its water more 'tightly'. Therefore, when these pulps are pressed the water from the once dried pulps is removed easier, and the resultant consistency is higher than that of the never dried pulp.

A third noticeable trend in the results is that the S. D. Warren bleached kraft presses to a higher consistency than either the S. D. Warren unbleached kraft or the Menash unbleached NSSC. Bleaching of papermaking fibers is known to destroy many of the external fibrils and, therefore, a number of cellulose-to-cellulose bonds, just as drying and rewetting of pulp is recognized as doing. Therefore, just as once dried pulp obtains higher consistencies than never dried pulp in the dynamic press simulator, so must bleached pulp when compared to unbleached pulp.

After discussing my results with a researcher familiar with the dynamic press simulator, I became aware that the results were not as consistent as they should have been. A comparison of the press used for this study and the original dynamic press simulator was made. It was discovered that the original press was designed with bearings in the upper plate to produce a nearly frictionless drop along the posts. The press used for this study incorporated bushings rather than bearings in the upper steel plate. Therefore, when the upper steel plate and hammer were dropped friction developed between the posts and the bushings, dissipating some of

the energy. As the hammer struck the anvil, it did so with less energy than it would have with a nearly frictionless fall. The development of the friction, therefore, resulted in the erroneous results.

CONCLUSIONS

The following conslusions can be reached from this study:

1. Higher consistencies out of the press section are obtained with the freeness level of 500; lower consistencies are obtained with the 300 freeness level.

2. Pulps that have been previously dried reach higher consistencies in the press section than pulps that have never been dried.

3. The S. D. Warren bleached kraft presses to a higher consistency than either the S. D. Warren unbleached kraft or the Menasha unbleached NSSC.

4. The development of friction between the posts and the bushings reduces the energy with which the hammer strikes the anvil.

RECOMMENDATIONS

The dynamic press simulator is proving its worth as a valuable experimental tool in the area of wet pressing. Work with this instrument should continue in the future.

Owing to the results obtained with this experiment, the dynamic press simulator should be perfected prior to further studies. Since relevant results appear to be dependent upon a nearly frictionless drop, the bushings need to be either improved or replaced with bearings. Possibly the bushings will be suffi-

cient if well greased prior to each drop.

When the press and its procedure are in good working condition, some very useful and interesting studies can be made concerning wet pressing. In time, our dynamic press simulator should be used for studies involving drilled presses, grooved presses, plain presses, or hot presses. The press could also be used to study the effects of various parameters such as roll diameter, cover hardness, and felt caliper.

The dynamic press simulator has unlimited possibilities for our labs.

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APPENDIX

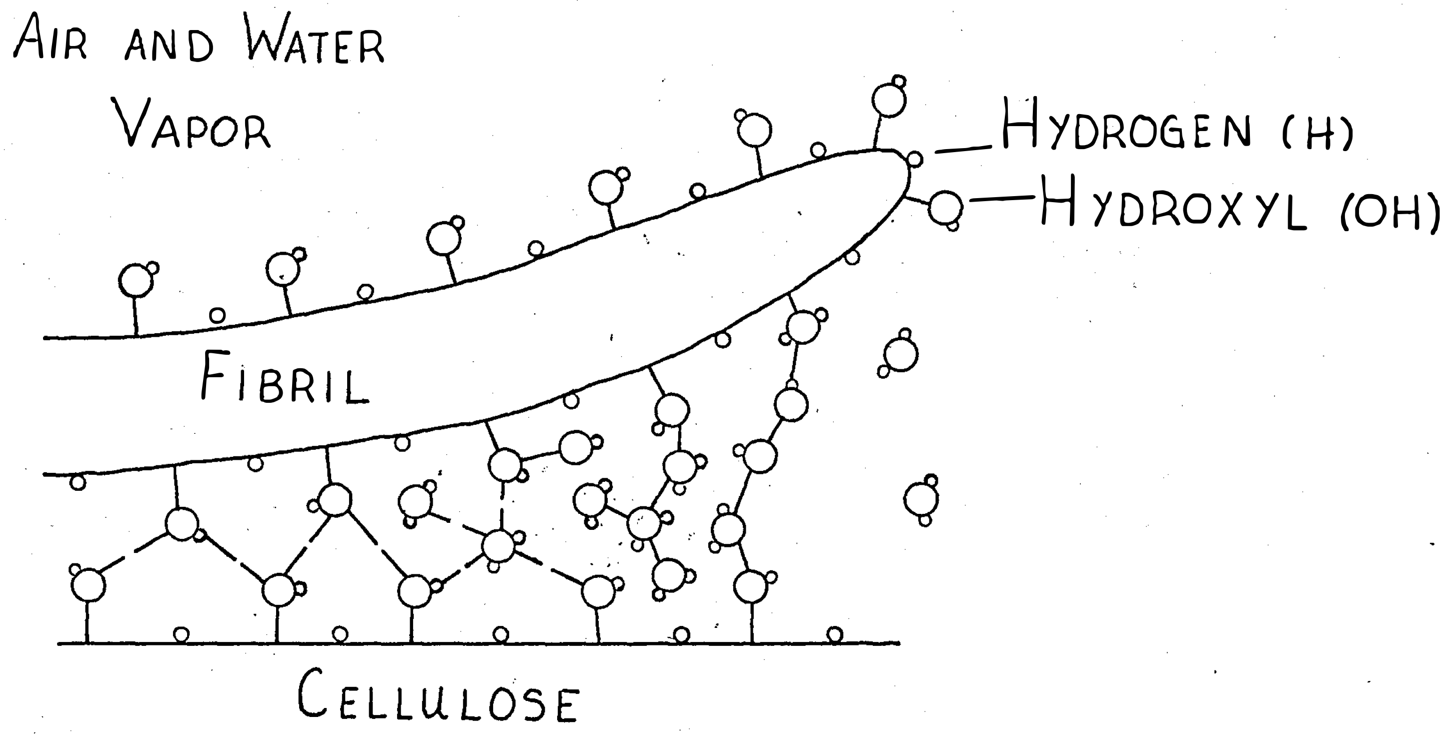

FIG. 1. REMOVAL OF WATER

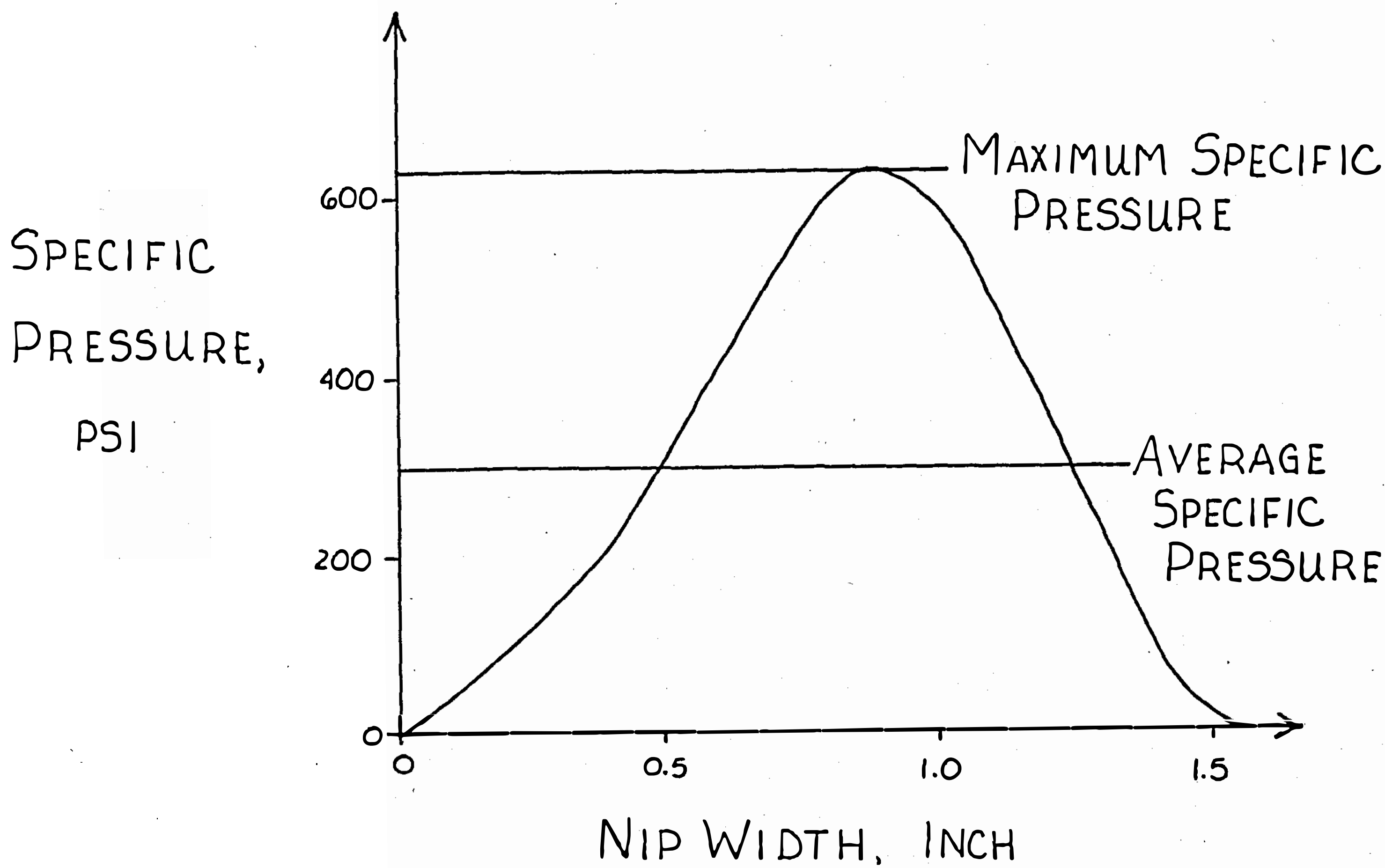

FIG. 2. PARAMETERS OF PRESSING

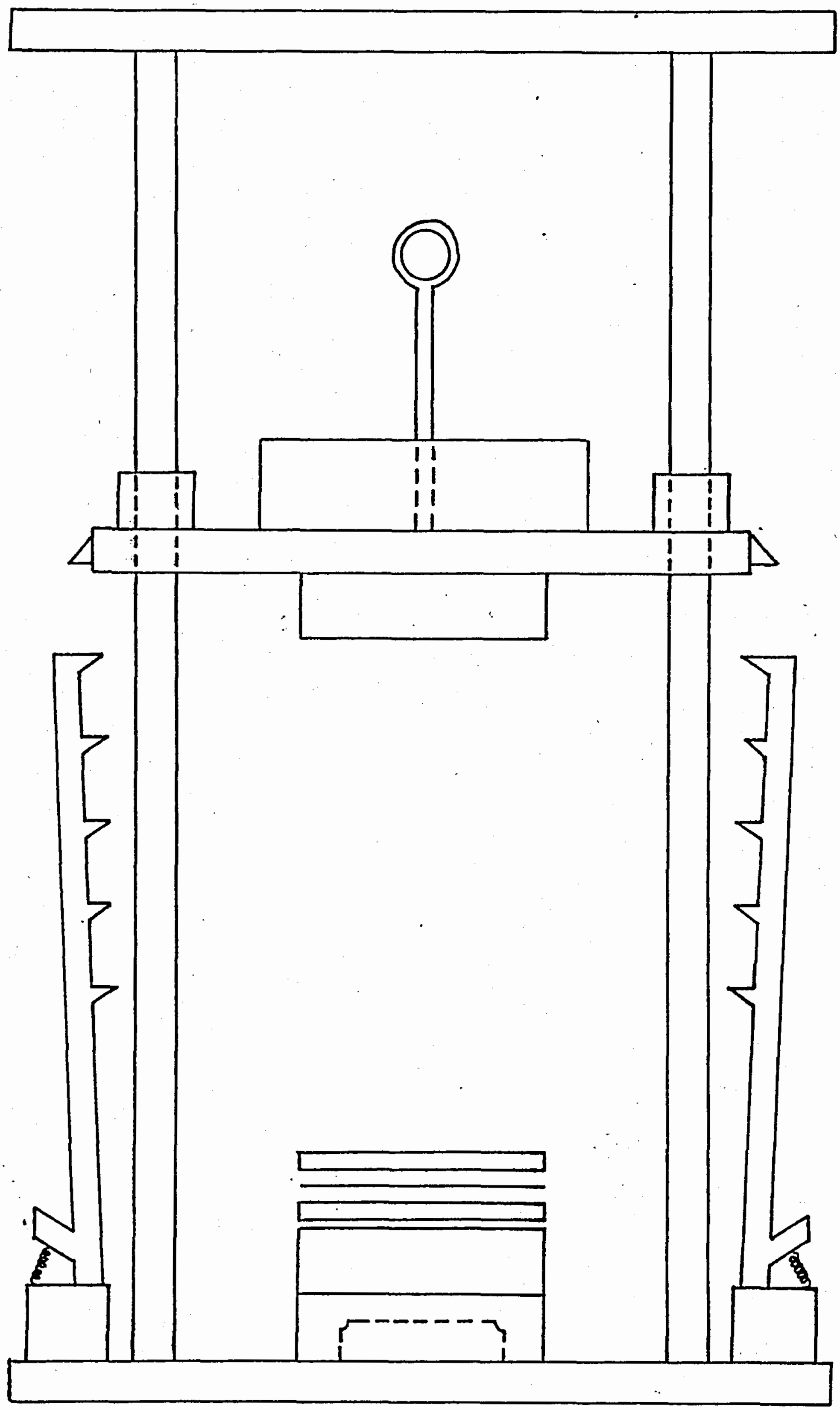

FIG. 3. DYNAMIC PRESS SIMULATOR

CALCULATIONS OF PRESS IMPULSES

$$\text{PRESS IMPULSE} = [mV_1 - m(-V_2)] / A$$

WHERE :

m = MASS OF HAMMER
V_1 = VELOCITY BEFORE IMPACT
V_2 = VELOCITY AFTER IMPACT
A = AREA OF SAMPLE

THEORETICALLY, $V_1 = (2gh_1)^{1/2}$; $V_2 = (2gh_2)^{1/2}$

WHERE :

g = ACCELERATION OF GRAVITY
h_1 = DROP HEIGHT
h_2 = REBOUND HEIGHT

$$A = \pi r^2 = (\pi)(1.75\,\text{IN}/12\,\text{IN/FT})^2 = 0.06678\ \text{FT}^2$$

I. 10 LBS. WEIGHT + 10 LBS HAMMER = 20 LBS TOTAL

$$V_1 = \sqrt{(2)(32\,\text{FT/S}^2)(2\,\text{FT})} = 11.314\ \text{FT/S}$$

$$V_2 = \sqrt{(2)(32\,\text{FT/S}^2)(4/12\,\text{FT})} = 4.619\ \text{FT/S}$$

$$\text{P.I.} = [(20\,\text{LBS})(11.314\,\text{FT/S}) + (20\,\text{LBS})(4.619\,\text{FT/S})] / (0.06678\,\text{FT}^2)$$
$$= 4771.8\ \text{LB/FT}\cdot\text{S}$$

II. 20 LBS. WEIGHT + 10 LBS HAMMER = 30 LBS TOTAL

$$V_1 = \sqrt{(2)(32\,\text{FT/S}^2)(2\,\text{FT})} = 11.314\ \text{FT/S}$$

$$V_2 = \sqrt{(2)(32\,\text{FT/S}^2)(2/12\,\text{FT})} = 3.266\ \text{FT/S}$$

$$\text{P.I.} = [(30\,\text{LBS})(11.314\,\text{FT/S}) + (30\,\text{LBS})(3.266\,\text{FT/S})] / (0.06678\,\text{FT}^2)$$
$$= 6549.9\ \text{LB/FT}\cdot\text{S}$$

III. 30 LBS WEIGHT + 10 LBS HAMMER = 40 LBS TOTAL

$V_1 = \sqrt{(2)(32\ FT/S^2)(2\ FT)} = 11.314\ FT/S$

$V_2 = \sqrt{(2)(32\ FT/S^2)(2/12\ FT)} = 3.266\ FT/S$

$P.I. = [(40\ LBS)(11.314\ FT/S) + (40\ LBS)(3.266\ FT/S)] / (0.06678\ FT^2)$

$= 8733.2\ LB/FT \cdot S$

IV. 40 LBS. WEIGHT + 10 LBS HAMMER = 50 LBS TOTAL

$V_1 = \sqrt{(2)(32\ FT/S^2)(2\ FT)} = 11.314\ FT/S$

$V_2 = \sqrt{(2)(32\ FT/S^2)(2/12\ FT)} = 3.266\ FT/S$

$P.I. = [(50\ LBS)(11.314\ FT/S) + (50\ LBS)(3.266\ FT/S)] / (0.06678\ FT^2)$