An investigation of the effects of pressure and time on the specific gravity, moisture content and volume of wood chips in a water slurry
by Ronald Earl Schmidt

A thesis submitted to the Graduate Faculty in partial Fulfillment of the requirements for the degree of MASTER OF SCIENCE in Civil Engineering
Montana State University

Abstract:
This thesis is an investigation of the effects of time of soaking and intensity of system pressure on the change of moisture content, volume and specific gravity of lodgepole pine chips immersed in water= Tests were performed on eight sizes of cut block samples, four sizes of screened chips and bulk chip samples. The samples were immersed in water under pressure; the increase in weight due to moisture absorption, time of immersion and system pressure were recorded at selected time intervals.

The weight change of the chips due to water absorption was measured by a modified hydrometer. The mechanics of the hydrometer operation and the procedures for its use are presented..

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The change in moisture content, and therefore the change in specific gravity, of immersed chips subjected to variations in pressure for a given length of time may be estimated from the expressions developed.

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AN INVESTIGATION OF THE EFFECTS OF PRESSURE AND TIME ON THE SPECIFIC GRAVITY, MOISTURE CONTENT AND VOLUME OF WOOD CHIPS IN A WATER SLURRY

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Ron E. Schmidt

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ABSTRACT

This thesis is an investigation of the effects of time of soaking and intensity of system pressure on the change of moisture content, volume and specific gravity of lodgepole pine chips immersed in water.

Tests were performed on eight sizes of cut block samples, four sizes of screened chips and bulk chip samples. The samples were immersed in water under pressure; the increase in weight due to moisture absorption, time of immersion and system pressure were recorded at selected time intervals.

The weight change of the chips due to water absorption was measured by a modified hydrometer. The mechanics of the hydrometer operation and the procedures for its use are presented.

Data obtained from the tests were used with accepted expressions for moisture content, wet specific gravity and volumetric expansion to develop empirical relations which give: (1) the change in moisture content as a function of the system pressure, (2) the time required for the moisture content to stabilize as a function of the system pressure, and (3) the change in the specific gravity of a sample as a function of the moisture content change and the oven dry specific gravity of the sample.

The change in moisture content, and therefore the change in specific gravity, of immersed chips subjected to variations in pressure for a given length of time may be estimated from the expressions developed.

NOTATION

The following notation is used in the derivations and mathematical expressions that appear in the discussions of this investigation. It should be noted that some terms have the same notation and physical significance as terms used in soil mechanics. Subscript notation may differ somewhat from the standard soil mechanics notation. Other terms are unique to this discussion and have been defined specifically for use in this paper.

e	- void ratio of a wood chip or chip sample
ex	- volumetric expansion (percent of dry volume)
F.S.P.	- fiber saturation point or moisture content at fiber saturation point
m	- moisture content - weight of water in a sample divided by weight of the oven dry sample
p	- pressure acting on immersed chips lb/in^2 (absolute or gage as indicated in text)
S.G.	- specific gravity of a wet sample
S.G. dry	- specific gravity of oven dry sample
S.G.$_g$	- specific gravity of dry sample at green volume
S.G.$'$	- specific gravity of wood fiber substance
V_t	- total volume of chip
V_{od}	- volume of an oven dry chip
V_a	- volume of air in a chip sample
V_{od}	- volume of oven dry wood fiber in a given chip or chip sample
V_v	- volume of voids in a chip sample

v_ω	-	volume of water in a chip sample
W_t	-	total weight of chip sample wet or dry
W_{od}	-	weight of oven dry wood substance in a given chip or chip sample
W_ω	-	weight of water in a given chip or chip sample
Δm	-	change in moisture content
ΔW	-	change in weight of chip as it absorbs moisture
ΔV	-	change in volume of chip as it absorbs moisture
γ	-	unit weight of wet sample
γ_{od}	-	unit weight of dry sample
γ_ω	-	unit weight of water = 62.4 16/cu. ft.
$\%S$	-	percent saturation

The following is a list of the basic relationships between some of the factors listed above:

$$e = V_v / V_{od}$$

$$ex = \frac{V_t - V_{od}}{V_{od}} = \frac{\Delta V}{V_{od}}$$

$$m = \frac{W_t - W_{od}}{W_{od}} = \frac{W_\omega}{W_{od}} = \frac{\Delta W}{W_{od}}$$

$$\%S = \frac{V_\omega}{V_v} \times 100 \quad \text{or} \quad \frac{m}{m_{sat}} \times 100$$

I. INTRODUCTION

A. Introduction

Vast areas of the North American continent contain stands of timber which because of its size or quality is not suitable for saw timber, but is suitable for pulpwood and wood fiber products. The value of this timber resource is estimated in millions of dollars annually for federal, state and private landowners. However, thousands of acres of such timber are not harvested because of economic limitations: the cost of obtaining the wood for processing is higher than the value of finished products.

Harvesting costs can be roughly placed into two categories: cutting and transporting. The first includes all items involved in making the standing trees ready for transporting, such as felling, limbing, bucking, clearing and slash disposal. The second includes such cost items as purchase, operation and maintenance of skidding, loading and hauling equipment, road construction and maintenance. Land management problems of erosion and stream sedimentation, caused by road construction and logging operations, add additional costs which are not easily evaluated but are justifiably included in harvesting costs.

B. Pipeline Transport of Chips

The study of the transportation cost problem has led to the consideration of the possible use of pipelines for transporting wood chips. Pipeline transportation of other solids such as coal, sand, and mineral ores has been in use since the early 1950's. In 1951 and 1952 the U.S. Bureau of Mines and the British Hydromechanics Research Association conducted experiments with such systems for coal. In 1956 the Pittsburgh Consolidation Coal Co. used a 108-mile line to deliver 3,400 tons per day from their mines in Georgetown, Ohio to Cleveland. The American Gilsonite Company, in 1957 began operating a 72-mile, 6-inch Pipeline to deliver 1100 tons per day of Gilsonite to Grand Junction, Colorado.

Along with the increased use of such pipeline systems came advances in the technology of hydraulic transport of solids. Technical criteria are now adequate for most applications. However, the transportation of wood chips by pipeline presents some hydraulic problems in addition to those encountered in the pipelining of mineral or non-fiberous solids. Such problems are:

1. Specific gravity of the material varies among species of wood and within samples of a given species.
2. Specific gravity of the wood changes with changes in moisture content.
3. Volume of the wood will change up to certain limits as moisture content increases.
4. Particles to be transported are extremely variable in size and shape and are much larger than those of materials successfully transported by pipeline to date.

C. Statement of Problem

A brief investigation of items 2 and 3 above led to the following hypothesis: The specific gravity and volume change are functions of the moisture content of the wood chips and that moisture content is affected by time of immersion and the pressure to which the immersed sample is subjected. This is based on the following observations:

As a piece of wood absorbs water, its weight and volume increase. The ratio of the weight increase to the volume increase is such that the bulk unit weight and bulk specific gravity also increase. If sufficient moisture is absorbed, the specific gravity will exceed unity, and the chip will sink. The amount of water absorbed increases with length of time of soaking. Pressure affects the amount and rate of water absorption. Therefore, moisture content is a function of the pressure acting on a wood-water slurry and the time of soaking. Since the specific gravity of wood is related to moisture content, any evaluation of the change in moisture content can be used to evaluate changes in chip specific gravity.

The purpose of this investigation was to determine and evaluate the effects of time and pressure on the specific gravity, moisture content and volume change of wood chips in a water slurry. An experimental laboratory program was conducted to study this problem. This thesis is a report of that work.

D. Review of Literature

The field of pipeline transportation of wood chips is new, and the literature on the subject is quite limited. Literature directly related to the change in the specific gravity, moisture content and volume was not found. Faddick (4) and Elliott (3) briefly alluded to this problem in discussing their initial studies of model pipelines.

The major portion of Faddick's work was the presentation of data and results of studies on pressure losses in model pipelines. He made only general statements about the change in specific gravity and did not account for it in his work. Chip pipeline studies have been carried out by the Pulp and Paper Research Institute of Canada (3), (4) and additional studies were conducted during the summer of 1964. However, evidence indicates that no direct study of the specific gravity of the wood chips has been or will be conducted. The Shell Pipeline Corporation has also done some work in the field of chip pipelines. This work is held confidential, however, and it is not known if any studies directly related to specific gravity and moisture content were performed.

The Forest Products Laboratory of the U.S. Forest Service has published several reports that discuss the effects of moisture content on the various physical properties of wood, including specific gravity and volume change. (10), (11) Although the reports reviewed by the author did not discuss the specific problem of wood chips in a pressurized water slurry, they were of value in the development of the relationships that are discussed later. Other publications of the Forest Products Laboratory and publications of the Pulp and Paper Research Institute of Canada contain information on the absorption of pulping liquors into wood chips in pressure vessels. However, since the physical and chemical characteristics of the wood are changed by such liquors, and the temperatures of such pulping processes are much higher than the temperatures to be encountered in a pumping operation, this information can not be used to predict absorption of clear water by wood chips.

E. Need for Study

The value of investigating the effects of time and pressure on the specific gravity of wood chips in water is found by considering a batch of chips injected into a pipeline system for transportation. The initial specific gravity of the solids will, in most cases, be less than unity, and the chips will tend to travel along the top of the pipe. When subjected to pressures necessary for pipeline operation, the chips may attain a specific gravity greater than unity and sink and then travel along the bottom of the pipe. Head loss in the line will decrease downstream pressures to a point where the chips may rise and float along at the top of the slurry.

Chips floating along at the top of the pipe would tend to congregate at high points of the line and could conceivably cause plugging of the system at these points. Similarly, chips traveling along the bed of the pipe could cause plugging at low points in the line. The probability of plugging would be reduced if a uniform distribution of chips throughout the cross section of the pipe could be attained. Such a distribution of chips is most likely to occur if the specific gravity of the chips is at or slightly below unity.

Faddick (4) suggests that a specific gravity greater than unity would be more desirable since the flow would then be more analogous to flow characteristics of other solids. However, he had no data to make a direct comparison of flow of chips at various values of specific gravity.

The pulp and paper industries are directly concerned with the moisture content of raw chips as it affects the amount of pulping liquor needed for the pulping process. These industries are also interested in the rate of absorption of pulping liquor into chips, which might have an initial moisture content higher than that of green wood due to the water absorbed during the pumping operation.

For these reasons the problem was considered worthy of investigation.

II. MATHEMATICAL ANALYSIS

A. Basic Specific Gravity, Moisture Content, and Volumetric Expansion Relationships

The experimental investigation of the relationship between the specific gravity of wood chips and the pressure acting on the wood-water slurry depends upon establishing a method for determining the specific gravity of the immersed chips when the mixture is pressurized. The following mathematical analysis of the physical properties of such a system are now presented to assist in establishing such a method.

Specific gravity, a dimensionless number, is defined as the ratio of the unit weight of a substance to the unit weight of water. Unit weight is defined as the weight of a substance divided by its volume and is expressed in pounds per cubic foot or grams per cubic centimeter. ($lb./ft.^3$, pcf or gm./cc.)

With the above definitions and using the notation given previously, specific gravity of a wood chip can be written

$$S.G. = \frac{1}{\gamma_\omega} \cdot \frac{W_t}{V_t} \quad (1)$$

The value of γ_ω can be easily obtained for any pressure and temperature by the use of physics, chemistry, or engineering handbooks such as Handbook of Chemistry and Physics (7) or Civil Engineering Handbook (6).

In the range of temperatures and pressures encountered in this study the unit weight of water is essentially constant. Therefore,

$$S.G. = K\left(\frac{W_t}{V_t}\right) \quad (2)$$

Specific gravity is then some function of the weight and volume of the material. As the values of weight and volume of woodchips are not easily obtained when the chips are in a pressurized wood-water mixture, it is necessary to consider the parameters that affect these properties in an attempt to develop procedures for ease in measuring these qualities.

Consider a single chip, wet or dry. Its total weight and volume can be expressed

$$W_t = W_{od} + W_w \tag{3}$$

$$V_t = V_{od} + \Delta V \tag{4}$$

Rewriting the expression for moisture content and volume expansion as given in the list of notations

$$W_w = m \cdot W_{od} \tag{5}$$

$$\Delta V = ex \cdot V_{od} \tag{6}$$

Using equations (5) and (6) in equations (3) and (4) we obtain

$$W_t = W_{od} + m W_{od} = (1+m) W_{od} \tag{7}$$

$$V_t = V_{od} + ex V_{od} = (1+ex) V_{od} \tag{8}$$

Substituting the above equations into (1) the expressions for specific gravity can be rewritten

$$S.G. = \frac{1}{\gamma_w} \cdot \left[\frac{(1+m) W_{od}}{(1+ex) V_{od}}\right] = \left[\frac{1+m}{1+ex}\right] \cdot S.G._{dry} \tag{9}$$

Since the dry specific gravity is obtained at atmospheric pressure, the problem becomes one of determining values of moisture content and volumetric expansion while the chip is pressurized in the water.

The specific gravity of wood is often expressed as a specific gravity based on dry weight and green volume (SG_g). Since this value is based on the green or maximum volume, it is expressed in terms of dry specific gravity as

$$S.G._g = \frac{W_{od}}{V_t \cdot \gamma_\omega} = \frac{W_{od}}{(1+ex)\,V_{od} \cdot \gamma_\omega} = \frac{S.G._{dry}}{1+ex_{max}} \qquad (9a)$$

where ex is the maximum volumetric expansion.

This expression is also valid for the specific gravity value based on volume at fiber saturation point since volumetric expansion has reached its maximum value at the fiber saturation point.

The value of specific gravity based on dry weight and volume at current moisture condition below the fiber saturation point is similarly expressed as

$$S.G._c = \frac{S.G._{dry}}{1+ex} \qquad (9b)$$

where ex is a function of m up to the fiber saturation point.

Multiplying either of the variations of dry specific gravity by the factor (1+m), which accounts for the added weight of the water in the sample, the actual specific gravity is obtained and is identical to equation (9).

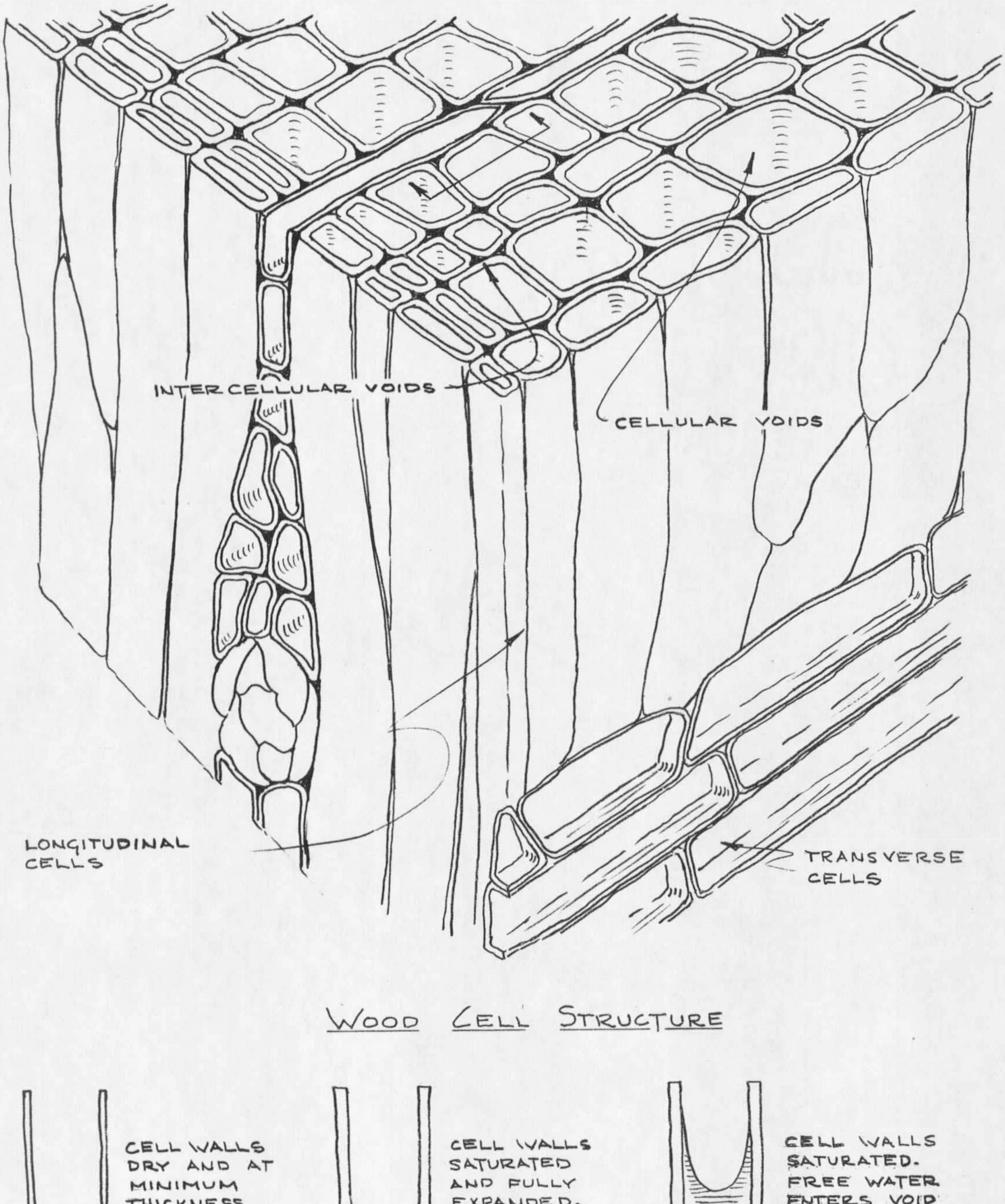
B. Moisture Absorption, Volumetric Expansion and Fiber Saturation Point

A discussion of the phenonemon of moisture absorption by wood samples is necessary before attempting a development of the methods for determining moisture content and volumetric expansion.

Moisture exists in wood in two conditions; as "free water", water existing in the cell cavities and intercellular spaces and as "absorbed water", water actually absorbed into the fibers and ray cells of the cell walls. (See Fig. 1) The presence or absence of free water has no effect on the bulk volume of the chip. Decreases or increases in absorbed water will cause shrinkage or expansion of the cell walls and thus affect total volume changes of the wood sample.

As green wood dries out, the free water is evaporated first without volume change of the wood. When all free water is gone the fibers are completely saturated with absorbed water. Further reduction in moisture will dry out the cell walls and cause shrinking of the sample. If initially dry wood is allowed to soak up moisture the process is reversed. First, the fibers in the cell walls absorb moisture with subsequent expansion until all fibers are completely saturated. At this point expansion stops and any additional water will begin to fill up the cell cavities. Complete saturation of the wood occurs when all cavities and intercellular spaces are filled.

Volume changes in wood are usually expressed as a shrinkage as the wood dries out. This approach is justified since wood in its natural state is very wet, with moisture content ranging as high as 150-200 percent. Shrinkage is then expressed as a percent of green volume. As this volume change is directly proportional to moisture content within the absorption range, the volumetric change may be developed as an expansion



WOOD CELL STRUCTURE

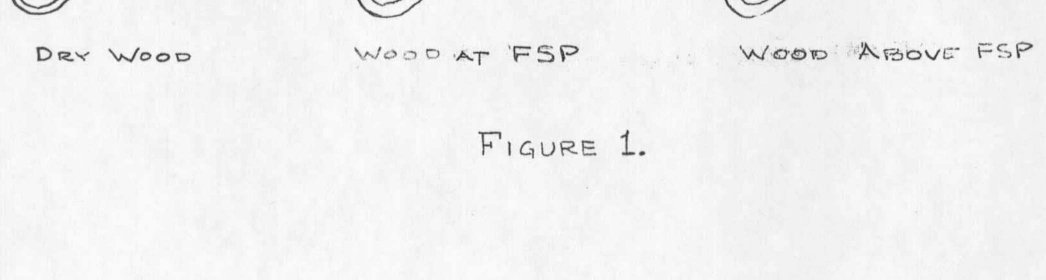


FIGURE 1.