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AN ABSTRACT OF THE THESIS OF Farid Piroozmandi for the Master of Science in Engineering: Mechanical presented March 1, 1985.

Title: Transient Flow Inverse Study Calculation of Unsaturated Permeability of Wood.

APPROVED BY MEMBERS OF THE THESIS COMMITTEE:

G.A. Spolek, Chairman

C.W. Savery

R.W. Koch

One of the major processes in lumber industry is wood drying. This process consumes large amounts of energy and capital, and due to the length of time it takes, it acts as a governing factor in lumber production levels. Development of improvements in processes and equipment used in wood drying can be expedited through computer simulation of various drying procedures. These numerical simulations depend on the accuracy of numerical models representing wood transport properties, including functional dependency of liquid permeability through wood with respect to local saturation level. Data available in

the literature mainly represent wood permeability properties at fully saturated levels. This is an indication of steady state flow methods used in determining these values which are based on wide spread use of similar methods utilized in studies on fluid flow through soil. This research determines unsaturated wood permeability using transient liquid flow methods that are more representative of actual drying process. Initially saturated wood samples are spun in a low speed centrifuge to induce liquid migration through the cell structures. Transient local moisture profiles along the sample are measured using a scanning gamma ray densitometer. Numerical integration and curve fitting procedures are used to process these data. Finally, utilizing liquid continuity equation the functional dependency of permeability with respect to saturation is calculated. Some permeability results appear to be reasonable when compared with actual wood behavior during drying. Measurement procedures prove to yield accurate results for moisture content and saturation levels in wood with less than 5% relative error in average saturation level of .75. However, due to natural inhomogeneities in wood cellular structure, the final calculated results for unsaturated permeability show high levels of uncertainty (up to 112% relative error).

TRANSIENT FLOW INVERSE STUDY CALCULATION
OF UNSATURATED PERMEABILITY OF WOOD

by

FARID PIROOZMANDI

A thesis submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE
in
ENGINEERING: MECHANICAL

Portland State University

1985

TO THE OFFICE OF GRADUATE STUDIES AND RESEARCH:

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NOMENCLATURE

A	Surface area
B	Body force; constant characterizing pore geometry
E	Wood sample height
EMC	Equilibrium moisture content.
FSP	Fiber saturation point.
F	Force; wood sample length
g	Gravitational acceleration.
k	Permeability.
(L)	Upper range location in wood sample.
(l)	Lower range location in wood sample.
L	Length
L_c	Characteristic dimension of pore space
L_{wd}	Absorption length (dry wood).
L_{wd+w}	Absorption length (wet wood).
M	Moisture content.
m	Mass
$\dot{m}$	Average volume rate of evaporation of liquid
N	Gamma ray count.
n	Number of locations scanned in wood sample.
P	Pressure.
q	Volumetric flux

R	Centrifugal arm length; radius of pit opening.
Re_{Lc}	Reynold Number.
r	Radius of capillary tubing.
r_1, r_2	Principal radii of curvature of interface between two phases.
S	Saturation.
S_n	Standard deviation.
t	Time.
V	Volume.
$\vec{v}$	Velocity.
W	Angular velocity.
y	Random number.
Z	Position.
$\emptyset$	Void fraction, porosity.
σ	Specific free energy of the interface (surface tension); standard deviation.
μ	Liquid viscosity.
λ	Mean free path of gas molecules.
ρ	Density.
$\bar{\rho}$	Average density.
μ_{Wd}	Wood gamma ray attenuation coefficient.
μ_W	Water gamma ray attenuation coefficient.
G	Specific gravity.
τ	Instrument dead time (gamma ray densitometer).
ψ	Volume fraction.

Subscripts

B	Bulk.
c	Capillary.
cw	Cell wall.
w	Water; wetting.
nw	non wetting.
wd	Wood.
ℓ	Liquid (water).
wd+w	Wet wood.
wd+EMC	Dry wood at equilibrium moisture content.
g	Gas; gravity.

"... if comparison be made with the sum total of all former human achievements it will be found that the discoveries, scientific advancement and material civilization of this present century have equalled, yea far exceeded, the progress and outcome of one hundred former centuries."

-Abdul Baha' (1844-1921)

CHAPTER I

INTRODUCTION

There is a well founded interest in the Pacific Northwest where the lumber industry is so large in developing a better understanding of the lumber drying process. In order for green wood to attain desirable strength and dimensional stability it has to be dried below a set saturation level. The drying process is done in industrial kilns where hot dry air is blown over lumber and moisture is removed from the surface of the wood. This process requires large supplies of energy and also is a major capital cost. To optimize the drying process a rather inexpensive approach is to study the effects of varying the various parameters involved in a computer simulation of the moisture transport process in wood.

Recent studies (Spolek 1981a, Spolek 1980) on the process of wood drying indicates that during the initial periods of drying, while wood is moist enough, moisture easily migrates from within the wood cell structures to the surface of the lumber. Thus, the governing factor on the drying rate is the rate at which moisture is removed from the surface of the wood. Consequently one would conclude that drying time can be reduced through enhancing convective transport during the initial period of the drying process.

At the later stages of the drying process this enhancing capability is no longer available, because now the governing factor on

drying time is the rate at which moisture migrates through low moisture content wood cells toward the surface. The point within the drying cycle where this occurs can be predicted through understanding the transport mechanisms in wood. The liquid transport phenomenon is modeled by using Darcy's law. The mathematical model is used to predict moisture flow in wood cell structure. Permeability, the flow coefficient in Darcy's law, is the measure of wood conductance for moisture transport and depends on wood saturation level. Therefore, the accuracy and reliability of the computer simulation model of the drying process is strongly dependent on an accurate functional representation of permeability with respect to saturation. It is the intent of this research to develop a reliable procedure for determining unsaturated permeability of different woods and to demonstrate the technique for Southern Pine.

CHAPTER II

BACKGROUND

The general subject of this report deals with fluid flow through porous material. In order to better understand the main factors involved in this process, some of the characteristics of porous materials are discussed. In addition to properties of porous medium the state of fluid in the medium is also explained briefly along with the factors that cause fluid flow. For a detailed discussion of fluid flow through porous material, the reader is referred to books by Collins (1961), Bear (1979), Dullien (1979), and Siau (1971). Books by Collins (1961) and Bear (1979) study the subject from a soil scientist point of view, i.e. water flow through layers of ground. Dullien (1979) and Greenkorn (1981) discuss the general area of porous media and fluid transport, and Siau (1971) specifically covers the fluid flow through wood.

A porous material is a solid that contains voids or holes. The holes are either connected or not, and are distributed throughout the material on a regular or random basis. The interconnected voids are the effective pore space in terms of fluid flow through the porous media. The porous media can be either consolidated as in wood or sandstone, or unconsolidated as in beach sand. Other examples of porous material are bread, human lung, or a package of glass beads. Because of the

complexity of pore structure of porous material the macroscopic properties of such material is studied.

One of the properties of porous material is its porosity. Porosity is the fraction of the total volume of the material which is occupied by voids. Porosity is a dimensionless number and is calculated as follows:

$$\phi = \frac{V_p}{V_B} = \frac{\text{Pore space volume}}{\text{Bulk Volume}}$$

Total porosity represents the total void space in the porous media, and effective porosity represents the interconnected void space. The value of porosity in a porous material depends on the shape and size of parts forming the material and also the pattern with which they are located with respect to each other. The range of porosity theoretically is between 0 and 1, where at $\phi=0$ the material is all solid with no void in it, and at $\phi=1$ there is no solid part and material is all void space. As an example porosity of Southern Pine wood is about 0.63 and porosity of sandstone is between 0.08 to 0.38 (Collins, 1961).

In order to calculate the porosity of porous material one should measure the volume of void space and also the total volume of the sample. There are various methods utilized to measure porosity (Collins, 1961; Siau, 1971). Here we will discuss two direct methods which will result in total and effective porosity values.

In the first method the bulk volume of sample is measured. Then the sample is crushed and void spaces within the sample are eliminated, and volume of the solid part is measured. Finally the porosity is calculated as follows:

$$\phi = \frac{V_{\text{void}}}{V_{\text{bulk}}} = \frac{V_{\text{bulk}} - V_{\text{solid}}}{V_{\text{bulk}}}$$

This method yields total porosity and is usually used for brick, ceramics and similar porous material.

The other method is called mercury injection (Collins, 1961). In this method porous sample is immersed in mercury. Because of high surface tension of mercury (surface tension of mercury is 484×10^{-3} N/m as opposed to that of water of 72.8×10^{-3} N/m) and its non-wetting properties under atmospheric pressure mercury will not enter the pore spaces. Therefore the total, bulk, volume of sample is determined by volume displacement of mercury due to immersion of the sample. Then the mercury chamber is closed and the hydrostatic pressure of mercury in the chamber is increased to a very great value. Mercury will enter the void spaces in the sample compressing the trapped air in them to a negligible volume. The volume of mercury injected is equal to the volume of void space. Knowing bulk volume and void volume, porosity is calculated. This method will yield in effective porosity but is not very precise because the volume of compressed air is not determined. Sample will be mercury contaminated after this test and may not be suitable for further experiment.

Another property of a porous media is permeability. Permeability is defined as a mechanical property of porous material characterizing the ease with which a fluid may be made to flow through the material by an applied pressure gradient. In brief, permeability is the fluid conductivity of the porous material. Permeability (k) is better explained through utilization of Darcy's law (for a discussion on Darcy's law refer to Chapter III, Mathematical Modeling) (Collins,

1961). A horizontal laminar flow of an incompressible newtonian fluid through porous material is formulated by:

$$\text{Darcy's law} \quad k = \frac{q\mu}{A(\Delta P/L)}$$

where

q = volumetric Flux [cm^3/sec]

μ = Dynamic (absolute) viscosity of fluid [centi pose = .01 gm/(cm.sec)]

A = Surface area [cm^2]

$\Delta P/L$ = Pressure gradient over length of porous material in direction of flow [atm/cm]

k = Porous material fluid flow permeability [darcy]

In other words, if a steady state flow of $1 \text{ cm}^3/\text{sec}$ of a fluid with one centipoise dynamic viscosity is induced through a cube of porous material with 1 cm sides (normal to a surface of the cube) by a pressure gradient of one atmosphere, then the porous media has a permeability of one darcy.

$$1 \text{ darcy} = \frac{1(\text{cm}^3/\text{Sec}) \cdot 1(\text{centipoise})}{1(\text{cm}^2) \cdot 1(\text{atm/cm})} = 9.87 \times 10^{-9} \text{ cm}^2$$

As is indicated, permeability has units of length square. Collins (1961) indicates that permeability is proportional to mean square pore diameter in a porous media, and the spread of pore size of passages of fluid flow has a governing factor in determining the value of permeability. A porous material that has the same permeability value in all directions, such as beach sand, is called isotropic. Porous materials that have different permeabilities in different directions, such as wood, are called anisotropic.

Permeability of a porous material may be expressed as hydraulic conductivity. This form of permeability is dependent on the measuring fluid's viscosity and density. In order to get the intrinsic permeability (the version that was specified using Darcy's law and is a function of the size and number of pore spaces) the following equation is used (Bear, 1979):

$$k = (\text{hydraulic conductivity}) \times \frac{\mu}{\rho g}$$

where: μ = viscosity

ρ = fluid density

g = gravitational acceleration

Hydraulic conductivity is mostly used by soil scientists who study water flow through layers of soil. In this report we will mainly utilize permeability (intrinsic permeability) because the results of the study can be applied to any liquid regardless of their viscosity and density.

One factor in the fluid flow that was used to express Darcy's law is that it should be a no slip fluid flow, that is, the fluid velocity at solid surfaces within the porous media should be zero. If a gas is used as flowing fluid it can show slip flow characteristics and the rate at which the gas will flow through the pore spaces will depend on its molecular mean free path (given the mean free path of gas molecules are smaller than pore size) which is dependent on the mean pressure at which gas is flowing. As one can anticipate, the actual permeability of a porous material to gas is higher than the permeability to liquid. The relation between gas permeability (k_g), and no slip liquid flow permeability (k) of a porous media is represented by klinkenberg equation (Collins, 1961).

$$k_g = k(1 + \frac{b}{p})$$

where: p = mean flowing pressure

b = constant characteristic of both the gas and porous medium

Siau (1971) has presented klinkenberg equation for flow through wood by:

$$k_g = k(1 + \frac{3.8\lambda}{R})$$

where: λ = mean free path of gas molecules (for air at 20°C,

$$\lambda = 1.03 \times 10^{-5} \text{ cm})$$

R = radius of pit opening (sample value 4 μm). Pits are

orifices connecting the wood cells together and fluid flows through them.

According to Darcy's law, permeability is a representation of the ratio of volumetric fluid flow divided by the pressure gradient that induces the flow. The same principal is used to measure the single phase, steady state fluid flow permeability of a porous material. A steady state fluid flow is induced on a porous material sample, the volumetric flux and pressure gradient is measured and then the permeability of sample is calculated. As an example of the permeability values Comstock (1970) has found the tangential permeability of Southern Pine wood to be between 0.5×10^{-4} to 3×10^{-4} darcy, and permeability of sand stone ranges between 5×10^{-4} to 3.0 darcy (Collins, 1961).

Based on the method that we have defined permeability, permeability is only dependent on the characteristics of the pore space in the porous material and the path that fluid flow has to follow. Therefore any factor that affects the pore space or the flow path will affect the value of permeability. Such factors as compaction of porous

media which will reduce porosity, and swelling of walls of passages in the media (as in clay) that will reduce pore space will cause a reduction in permeability (Collins, 1961). Another factor that can cause reduction of permeability is eliminating the paths that fluid can use to flow. For liquid flow in a porous media, liquid will establish routes to flow, in case the flow is reduced there will not be enough fluid to support all the routes and some of them will be eliminated which will cause permeability reduction (this subject will be discussed in more detail later on). One factor that can increase permeability is enlarging the pore spaces. This is sometimes done in sand stones through dissolving some parts of the pore space solid walls by the fluid. This phenomena is called leaching (Collins, 1961).

When a fluid is present in the porous material, saturation (s) is a dimensionless number that is used to express the amount of fluid present.

$$S = \frac{\text{volume of fluid in a medium}}{\text{total volume of voids in the medium}}$$

Saturation ranges between 0 and 1. At $S = 0$ no fluid exists in the medium, and at $S = 1$, the medium is filled with fluid. In studying the flow through porous media there are almost always two fluids involved. In the case of water and air flow through a media, the fluids are immiscible. Water is a wetting (w) fluid and air is a non-wetting (nw) fluid. In a medium that both these fluids co-exist each one has its own saturation level, and we should have:

$$S_w + S_{nw} = 1$$

To calculate the saturation level of a fluid one needs to know the void volume and also fluid volume in media. For example, wetting fluid

(water) saturation in a porous media with bulk volume V_B and porosity $\emptyset$ is:

$$S_w = \frac{V_w}{\emptyset V_B}$$

where: V_w = water volume

A direct method for calculation of saturation is through weighing the sample at dry stage, (w_1), and then weighing it when it is partially saturated with a liquid with density ρ_ℓ , (w_2). Calculating the maximum weight of liquid possible in the sample with ($\emptyset \rho_\ell g V_B$) the saturation is calculated by:

$$S_\ell = \frac{w_2 - w_1}{\emptyset \rho_\ell g V_B}$$

This method will yield the average saturation of the porous media. In formulation of this method the weight of the gas phase present in the sample is assumed negligible.

Another method that can yield local saturation levels in a porous media is through gamma radiation absorption (Brown, 1982; Spolek, 1981a). Gamma radiation is absorbed by hydrogen molecules. If a sample of porous material is partially filled with water, through scanning the sample with gamma radiation its local moisture content and respectively saturation level can be determined. This very method is used in this research and it will be discussed later in the report.

When a porous media is partially saturated with a wetting liquid, there exists a gas phase within the pore space in contact with liquid phase. The liquid forms a meniscus in the pore space. At the interface between the two fluids the force of surface tension (σ) of liquid pulls the liquid phase toward the gas phase. Therefore, in order to have

mechanical equilibrium gas phase pressure (P_{nw}) has to be greater than liquid phase pressure (P_w). The difference between these two pressures is called capillary pressure (P_c).

$$P_c = P_{nw} - P_w \quad (\text{Collins, 1961})$$

Capillary pressure is also calculated by Laplace's equation

$$P_c = \sigma \left(\frac{1}{r_1} + \frac{1}{r_2} \right)$$

where:

r_1, r_2 = principal radii of curvature of interface between the two phases.

σ = specific free energy of the interface (surface tension)

The values of r_1 and r_2 depends on the pore space, the smaller the pore spaces the smaller r_1 and r_2 would be which in turn will indicate a higher capillary pressure. In a porous material which is fully saturated with liquid, since there is no gas-liquid interface, there is no capillary pressure present. However, if one starts to drain out the porous material by applying a pressure gradient or body force, menisci of liquid start forming and capillary pressure becomes apparent. The lower the saturation, the smaller principal radii at the interface become and a higher pressure gradient would be required to oppose the capillary pressure and drain out more moisture. Eventually a stage is achieved whereby capillary pressure becomes so large the pressure gradient can not drain any more moisture out of the sample. Saturation at this stage approaches irreducible saturation level (S_{ir}) (Spolek, 1981b). As it is indicated in Figure 1, capillary pressure is a function of saturation in a porous material, at $S=1$ capillary pressure is zero and at saturation levels near S_{ir} capillary pressure is very high.

Figure 1. Capillary pressure versus saturation.

Figure 2. Liquid rise in capillary tubing.

Capillary pressure is usually measured through measuring the pressure gradient that is required to counteract it at equilibrium. One method of measurement called the gravimetric method (Collins, 1961) is used to calculate capillary pressure for two fluid phase (gas = non-wetting, nw; liquid = wetting, w) in a round capillary tubing, Figure 2.

Here P = pressure

ρ = density

r = radius of capillary tubing

g = gravitational acceleration

Z = height of liquid in capillary tubing

$$P_w(Z) = P_w(0) - \rho_w gZ \quad (a)$$

$$P_{nw}(Z) = P_{nw}(0) - \rho_{nw} gZ \quad (b)$$

(a) and (b) will result in

$$P_c = P_{nw} - P_w$$

$$P_c(Z) = P_c(0) + (\rho_w - \rho_{nw}) gZ$$

at $Z = 0$ we have full saturation therefore $P_c(0) = 0$

$$P_c(Z) = (\rho_w - \rho_{nw}) gZ$$

To model wood as a porous material Comstock (1970) has modeled wood as a series of interconnected cells that have tapered ends which overlap on the radial surfaces and contain pits (small holes less than 4 micrometers in diameter interconnecting wood cells together) only on these tapered ends, Figure 3. Figure 4, based on this model, represents the situation where two immiscible fluids are present, and the path through pits that liquid follows (Spolek, 1981a) in tangential fluid flow through wood. Comstock (1970) shows that wood is a highly

Figure 3.. Mechanistic model of softwood.(Comstock 1970)

Figure 4.. Moisture distribution for unsaturated mechanistic softwood model.(Spolek 1981a)

anisotropic material. The assumptions that Comstock (1970) makes for his model are as follows:

- "1. Wood cellular structure is homogeneous: ray cells and earlywood latewood differences are ignored.
2. Flow is through the cell cavity - pit system, and the pits offer the only significant resistance to flow.
3. Cells are square in cross section.
4. Pits are of uniform size and located only on the radial walls of the cells.
5. A sufficient number of cells are traversed so that end effects can be ignored.
6. Tracheids (cells) have tapered ends that overlap on the radial surfaces, but not on the tangential surfaces.
7. Pits are uniformly distributed on the overlapping portion, but lacking elsewhere."

Spolek (1981a) has used the same model and has studied the model when two fluid phases, air and water, are present. In his study, Spolek (1981b) has shown that capillary pressure behavior is dependent on the radius of lumens (inner parts of tracheids, wood cells) and not dependent on radius of pit openings. Figure 5 (Siau, 1971) represents an actual cell structure of wood. Typical dimensions for a softwood structure are as follows (Siau, 1971)

Tracheid length = 3500 micrometer

Tracheid diameter = 33 micrometer

Tracheid lumen diameter = 20-30 micrometer

Overall diameter of pit chambers of bordered pits = 6-30
micrometer

Gross structure of a typical hardwood. Plane TT is the cross section, RR is the radial surface, and TG is the tangential surface. The vessels or pores are indicated by P, and the elements are separated by scalariform perforation plates, SC. The fibers, F, have small cavities and thick walls. Pits in the walls of the fibers and vessels, K, provide for the flow of liquid between the cells. The wood rays are indicated at WR. AR indicates one annual ring. The earlywood (springwood) is designated S, while the latewood (summerwood) is SM. The true middle lamella is located at ML.

(Courtesy of U.S.D.A. Forest Service.)

Figure 5. Wood cell structure (Saiu, 1971).

Effective radii of pit openings = 0.01-4 micrometer

As is shown in Figure 4 fluid, in order to flow from one cell to another, has to go through pits. When wood is fully saturated with liquid all flow paths are open and permeability is high. However, when saturation drops the liquid meniscus in cells starts entering the tapered ends of the cells. When a pit is not covered by liquid, the liquid flow path through that pit discontinues and this will cause permeability reduction. In fact, at irreducible saturation the menisci in adjacent cells reach the point of overlap and the continuous liquid phase path is broken and liquid permeability goes to zero (Spolek, 1981b).

Most of the studies on wood permeability focus on steady state methods (Comstock, 1970; Stamm, 1963; Resch, 1964). The steady state method consists of inducing a steady state flow (gas or liquid) across a wood sample using a known pressure gradient. Then permeability of wood sample is calculated as the ratio of flow over the pressure gradient. Due to the steady state flow nature of the method, wood samples are kept fully saturated during the experiment and permeability results are all for saturated wood. The steady state method is a widely used method because it is most often utilized by soil scientists and experimentation methods are established. Soil scientists most often deal with a very homogeneous porous material (i.e. beach sand) and since in their studies usually direction of flow and body force on fluid is the same, they use a general term called flow potential that contains all the pressures acting on the fluid. In addition to simplification of pressure gradients since the soil studies mainly deal with water as fluid, a hydraulic conductivity is used as flow conductance parameter, instead of

permeability, which depends both on liquid and porous media properties. It is necessary to avoid these simplifications in wood permeability studies because in flow through wood different fluids are studied and also effects of different pressure inducing factors need to be studied.

To study the actual phenomenon of moisture transport through porous media, one should consider unsaturated stages of the phenomenon as well as fully saturated stages. Soil scientists have approached the problem through utilizing steady state flow of two immiscible fluids, air and liquid, while assuming macroscopic homogeneity within the porous media. Tessoro (1974) has applied the same technique to wood. In Tessoro's experiment a steady state flow of Nitrogen gas (N_2) and water was induced through wood and then permeability of each phase was calculated. Through varying the ratio of gas and liquid, Tessoro calculated the permeability at different saturation levels. Tessoro (1974) has concluded that wood permeability approaches zero when saturation drops below 70%. However, another study by Spolek (1981b) indicates that wood permeability does not drop to zero for saturation levels as low as 10%. Tessoro (1974) might have come to his conclusion based on the assumption that during steady state flow of two fluid, gas and liquid, both phases are uniformly distributed throughout the wood specimen. Conceptually gas phase forms large bubbles in the flow path obstructing the liquid flow. A layer of bubbles formed at the entrance to the porous structure of wood specimen reduces the liquid permeability to a large degree at an early stage of two phase flow causing a bottle neck effect. In two phase flow experiments, this bottle neck permeability is measured as the liquid permeability.

Another method used for calculating the unsaturated permeability of a porous medium is transient flow through the medium (Watson, 1966; Cassel, 1968). Watson (1966) studied the drainage of an initially saturated sand column, using a gamma radiation densitometer to measure the instantaneous local moisture content of the sand column. Having the plots of instantaneous local moisture content and flow potential (inducing pressure gradients) Watson calculated the flow velocity profile and flow potential gradients profiles through graphical integration and differentiation. By dividing the flow velocity over potential gradient, the hydraulic conductivity of sand column at different moisture content levels was calculated. Watson utilized Darcy's law for back calculating the hydraulic conductivity, and indicated that the results prove that Darcy's law can be used for flow through unsaturated porous media. Due to the nature of calculating hydraulic conductivity, back calculation of Darcy's law, and transient fluid flow, we will call this approach the "Inverse Study of Transient Flow". A similar method may be used to calculate the unsaturated permeability of wood. There are two main virtues inherent with this method. First, since actual moisture distribution can be measured along the wood sample without disturbing the drainage process, there is no requirement for assuming uniform distribution of liquid and gas through the wood sample. Second, during the experiment liquid is drained out of the initially saturated wood sample, the transient behavior of the sample more accurately represents the process of wood drying. As for the measurement of the local moisture content along the wood sample, it has been demonstrated that gamma ray absorption methods are capable of accurately measuring this value (Spolek, 1981a). Although gravitational

body forces are sufficient to maintain a transient flow condition in soil column, they are not large enough to do the same for wood samples of manageable size with their very small porous cellular structure. In order to maintain the required transient flow in the wood sample, an enhanced body force can be produced through utilization of a low speed centrifuge (Spolek, 1981a).

CHAPTER III

MATHEMATICAL MODELING

In order to develop a mathematical model representing fluid flow through porous media, Darcy's law will be applied to liquid phase continuity equation within the porous media. In studying the liquid flow through porous media some assumptions must be made. We assume a quasistatic flow; that is, the rate of change of the flow velocity is small, therefore one can assume that within the porous body the flow acceleration and deceleration averages to zero and no net force is generated due to acceleration or deceleration of liquid. A second assumption is that flow is laminar. Since the characteristic dimension L_c of the pore space is very small, the Reynold number

$$Re_{Lc} = \frac{\vec{V} \cdot L_c \cdot \rho}{\mu}$$

where Re_{Lc} = Reynold number

$\vec{V}$ = Average velocity

ρ = liquid density

μ = liquid dynamic viscosity

Re_{Lc} is very small, e.g. $Re_{Lc} < 10$, (or most of the time $Re_{Lc} < 1$).

In such flows, which are called creeping flow, the viscous forces acting on the liquid are much greater than the inertial forces.

Although Darcy's law is an empirical equation, we derive it from an intuitive basis (Collins, 1961). Consider steady state liquid flow through a porous material induced by a pressure difference ($P_a - P_b$) as in Figure 6 with positive in upward direction. The pressure force involved is

$$F_p = (P_a - P_b)\emptyset A\uparrow = -(P_a - P_b)\emptyset A \quad (1)$$

where: A = cross section area of porous material

$\emptyset$ = porosity of porous material

The gravitational body force on the liquid is:

$$F_g = \rho(\emptyset AL)g\downarrow = -\rho(\emptyset AL)g \quad (2)$$

where: ρ = liquid density

L = length of porous material in flow direction

g = gravitational acceleration

The viscous forces on the liquid act opposite to the direction of flow and are proportional to the viscosity of liquid and flow velocity gradient

$$F_\mu \propto \mu \frac{d\vec{V}}{dn}$$

where $\vec{n}$ is some unit vector normal to the local surface.

Since $\vec{V}$ is the flow average velocity

$$\vec{V} \propto \frac{\vec{q}}{A}$$

where $\vec{q}$ = volumetric fluid flux

Since on a macroscopic point of view the surface area of the pore spaces within the porous media is involved and these pore surfaces are related to the bulk volume of the media (AL) we can write the viscous force acting on the fluid as:

Figure 6. Flow through porous media, apparatus for developing Darcy's law.

$$F_{\mu} = B \mu \left(\frac{q}{A} \right) (AL) = B\mu qL \uparrow = + B\mu qL \quad (3)$$

where B = constant with dimensions of $[L^{-2}]$ as a characteristic of pore geometry.

In equilibrium the pressure gradient force should be counteracted by viscous and body force.

$$F_{\mu} \uparrow + F_g \downarrow = F_p \downarrow \quad (4)$$

$$B\mu qL - \rho(\emptyset AL)g = -(P_a - P_b)\emptyset A \quad (5)$$

$$q = \frac{-(P_a - P_b)\emptyset A + \rho(\emptyset AL)g}{B\mu L} = \frac{\emptyset}{B} \cdot \frac{1}{\mu L} [-(P_a - P_b)A + \rho(AL)g] \quad (6)$$

Taking $k = \frac{\emptyset}{B}$ as a constant characteristic of porous media we will have:

$$q = \frac{-kA}{\mu L} [(P_a - P_b) - \rho gL] = \frac{-kA}{\mu L} [\Delta P - \rho Lg] \quad (7)$$

$$q = \frac{-kA}{\mu} \left(\frac{\Delta P}{L} - \rho g \right) \quad (8)$$

$$\frac{q}{A} = v = \frac{-k}{\mu} \left(\frac{\Delta P}{L} - \rho g \right) \quad (9)$$

Equation (9) is called Darcy's law and k is permeability of the porous media. The negative sign indicates that fluid flow is in the direction of pressure reduction. The differential form of Darcy's law is:

$$\vec{V} = \frac{-k}{\mu} (\nabla P - \rho \vec{g}) \quad (10)$$

or, when Z is in the direction of the gravitational acceleration

$$v = \frac{-k}{\mu} \left(\frac{dP}{dZ} - \rho g \right) \quad (11)$$

Darcy's law is also valid for variable flow rates because viscous forces dominate inertial forces.

Liquid phase continuity equation is

$$\nabla \cdot \vec{V}_\ell = 0 \quad (12)$$

where we assume that liquid phase is incompressible.

Through defining volume fraction for liquid (ψ_ℓ)

$$\psi_\ell = \frac{V_\ell}{V} = \frac{\text{Liquid Volume}}{\text{Total Bulk Volume}} \quad (13)$$

and volume averaging within the porous media, Spolek (1981a) has developed the following liquid phase continuity equation from equation (12).

$$\frac{\partial}{\partial t} (\rho_\ell \psi_\ell) + \nabla \cdot \langle \rho_\ell \vec{V}_\ell \rangle + \langle \dot{m} \rangle = 0 \quad (14)$$

where:

t = time

ρ_ℓ = liquid density

$\vec{V}_\ell$ = liquid velocity

$\dot{m}$ = average mass rate of evaporation of liquid

$\langle \rangle$ = average values

Within a porous material the rate of liquid evaporation and vapor condensation averages to zero. Therefore

$$\langle \dot{m} \rangle = 0 \quad (15)$$

Since liquid is assumed to be incompressible, and considering an uni-directional fluid flow we will have:

$$\frac{\partial}{\partial t} (\psi_\ell) + \frac{\partial}{\partial z} (V_\ell) = 0 \quad (16)$$

Since

$$\psi_\ell = \frac{S\emptyset (\text{Bulk volume})}{\text{Bulk volume}} \quad (17)$$

where S = saturation level; then

$$\frac{\partial(S\emptyset)}{\partial t} = - \frac{\partial(V_\ell)}{\partial z} \quad (18)$$

Applying equation (10) on equation (18), and assuming unidirectional flow we will have:

$$\frac{\partial(S\emptyset)}{\partial t} = \frac{-\partial}{\partial Z} \left[-\frac{k}{\mu} \left(\frac{\partial P}{\partial Z} - \rho g \right) \right] \quad (19)$$

assuming $\emptyset$, porosity, is constant (i.e. the solid part of porous media is rigid) we will have

$$\emptyset \frac{\partial S}{\partial t} = \frac{\partial}{\partial Z} \left[\frac{k}{\mu} \left(\frac{\partial P}{\partial Z} - \rho g \right) \right] \quad (20)$$

In equation (20) the $\frac{\partial P}{\partial Z}$ term refers to liquid pressure gradient. Spolek (1981b) indicates that liquid pressure is related to gas pressure and capillary pressure present in the porous media at unsaturated stages. Therefore

$$\nabla P_\ell = \nabla P_g - \nabla P_c \quad (21)$$

where

P_ℓ = liquid pressure

P_g = gas pressure

P_c = capillary pressure

However, in a quasi-static liquid flow through porous media the pressure gradient required for gas to replace drained liquid is very small and one can assume that gas pressure during the liquid flow remains unchanged (Spolek, 1981a).

$$\nabla P_g \approx 0 \quad (22)$$

then

$$\nabla P_\ell = -\nabla P_c \quad (23)$$

replacing the liquid pressure gradient with its equivalent capillary pressure in equation (20) we will have

$$\emptyset \frac{\partial S}{\partial t} = \frac{\partial}{\partial Z} \left[\frac{k}{\mu} \left(-\frac{dP_c}{dZ} - \rho_\ell \vec{g} \right) \right] \quad (24)$$

since $\vec{g}$ is in negative direction of Z by using chain rule and remembering that capillary pressure is a function of saturation we will have:

$$\mu \frac{\partial s}{\partial t} + \frac{\partial}{\partial Z} \left[\frac{k}{\mu} \left(\frac{\partial P_c}{\partial s} \cdot \frac{\partial s}{\partial Z} - \rho_l g \right) \right] = 0 \quad (25)$$

Integrating equation (25) on Z from $Z=0$ to $Z=L$ we will have:

$$\begin{aligned} \mu \int_Z \frac{\partial s}{\partial t} dZ &= k(s(0)) \left[\left(\frac{\partial P_c}{\partial s} \right)_0 \cdot \left(\frac{\partial s}{\partial Z} \right)_0 - (\rho_l g)_0 \right] \\ &\quad - k(s(L)) \left[\left(\frac{\partial P_c}{\partial s} \right)_L \cdot \left(\frac{\partial s}{\partial Z} \right)_L - (\rho_l g)_L \right] \end{aligned} \quad (26)$$

to get to equation (26) we have assumed that fluid flow is isothermal and therefore liquid viscosity is constant. Also we are treating permeability a function of saturation.

Let

$$\left[\frac{\partial P_c}{\partial s} \right]_Z = C(s(Z)), \quad \left[\frac{\partial s}{\partial Z} \right]_Z = S'(Z), \quad \text{and } \rho_l g|_Z = B(Z)$$

then

$$k(s(L)) = \frac{k(s(0)) [C(s(0)) \cdot S'(0) - B(0)] - \mu \int_Z \frac{\partial s}{\partial t} dZ}{C(s(L)) \cdot S'(L) - B(L)} \quad (27)$$

Equation (27) can be used to calculate permeability of a porous media. Consider an experiment where an initially saturated porous material sample is drained so that one end of sample ($Z=0$) is kept continually at full saturation for reference and the drainage flow is induced through a body force $B(Z)$ on the liquid. Here $+Z$ is in the opposite direction of fluid flow. If one can measure the instantaneous local saturation levels of the sample, and also can calculate the functional dependency of capillary pressure on saturation, knowing the

fully saturated permeability of the sample $k(s(0))$ and also its porosity $\emptyset$ along with the liquid viscosity μ , it is possible to calculate the porous media permeability at the saturation level at location $Z=L$.

In a system developed by Spolek (1981a) and utilized by Brown (1982), an initially saturated wood sample is placed in a cup and then is spun in a centrifuge. The body force induced on the liquid within wood will cause the liquid to drain out of the wood. The cup holding the sample will provide a level of water at one end ($Z=0$) of wood sample to ensure full saturation at that end (Figure 7). A gamma radiation densitometer is used to measure local moisture content within wood between periods of run. Detailed discussion of the experimentation method will be done in Chapter IV "Experimental Procedure".

Utilizing this system the body force term on the liquid within wood is calculated by:

$$B(Z) = \rho_{\ell} g = \rho_{\ell} w^2 (R-Z) \quad (28)$$

where:

ρ_{ℓ} = liquid density

w = angular velocity of centrifuge

R = centrifuge arm (Figure 7)

Z = distance from liquid surface kept within the cup

After the specimen has been in the centrifuge and the body force can induce no more moisture drainage (steady state equilibrium stage) capillary pressures within the wood is counteracted by the body force.

$$\text{Since } \frac{\partial P_{\ell}}{\partial Z} = -\rho_{\ell} g \quad (29)$$

and equation (23) indicates

$$\frac{\partial P_{\ell}}{\partial Z} = - \frac{\partial P_c}{\partial Z}$$

Figure 7. Wood sample housing cup schematic and centrifuge notation.

we have

$$\frac{\partial P_C}{\partial Z} = \rho_L w^2 (R-Z) \quad (30)$$

Integrating equation (30) over Z and remembering that capillary pressure at full saturation ($Z=0$) does not exist ($P_C=0$ at $Z=0$) we will have

$$P_C = \rho_L w^2 Z (R - Z/2) \quad (31)$$

Utilizing equations (31) and (28) along with the saturation profiles $S(Z,t)$ generated by the gamma radiation densitometer one can solve equation (27) for unsaturated permeability values $k(s(L))$.

CHAPTER IV

EXPERIMENTAL PROCEDURE

Experiments were conducted using Southern Pine as the test wood species. Southern Pine is a widely used softwood, and its large permeability allows faster moisture movement, therefore reducing experimental time. The wood was initially in flat sawn, green, two by six lumber. The specimens were cut in rectangular blocks of about 9 cm x 5 cm x 5 cm. The long side paralleled the direction of intended water movement, grain orientation was considered while cutting the samples.

Initial saturation level of specimens was increased to 80%-90% through water impregnation. The specimens were submerged in water and subjected to alternating periods of low pressure (3 in. Hg) and high pressure (atmospheric), causing water to replace the air that was removed during the low pressure cycles.

The specimens (six at a time) were loaded into a centrifuge and spun. The angular velocities used in experimentation are detailed in table I.

The spin generated the body force required to induce liquid motion. The higher RPM's which generated higher body forces did not affect the permeability of samples under study because according to Haugen (1970) permeability in porous media is independent of the driving pressure gradient. Special plastic cups were used to house the specimen. Close to the end of each cup a hole provided an outlet to

Table I

SPECIMEN CENTRIFUGE SPIN DATA

Specimen #	Angular Velocity RPM	Angular velocity change occurred at spin period #	Total number of spin periods
1 to 6	500	-	8
7 to 12	845 and 580	6	9
13 to 18	200 and 360	8	11

drain excess water; it also provided a constant reservoir of water to the bottom of the specimen. At the bottom ($Z=0$, free water surface) of the specimen due to existence of water a full saturation condition was maintained, Figure 7. The cups were sealed to inhibit air drying of samples during the experiment. These precautions were taken in order to achieve the objective of isothermal moisture movement through wood where the only forces on the water within wood cells were body forces and capillary forces.

Periodically, after specimens were spun for a period of time ranging from one to twenty days, they were removed from the centrifuge and placed in the scanning apparatus. The scanning apparatus (Figure 8) consists of a gamma radiation source, a radiation detection device, and a mechanical housing that moves the specimen. The scanning gamma ray densitometer measures the local moisture content at a specific location within the specimen by measuring the attenuation of a collimated beam of gamma rays as it passes through the wood specimen. Since this measurement indicates the attenuation of radiation caused by wood, water, and the plastic cup container, the results are compared with dry wood in plastic cup container scanning results to find what portion of

Figure 8. Scanning gamma ray densitometer.

results correspond to that caused by water. By controlling and measuring the position of the radiation beam along the wood, the moisture profile is determined. The beam position was controlled by a traverse mechanism driven by a micro computer actuated stepper motor. The positions were measured with respect to the side drain hole in the housing cup because that position corresponded to the full saturation level. The gamma beam attenuation was measured by a pulse counter which was attached to the same micro computer. Thus, gamma count data acquisition was controlled by the micro computer. The local gamma counts along with other data such as sample weight, dimensions, and the time between runs, which were manually measured and then entered into the computer, were automatically stored on cassette tape.

Spinning and scanning of each specimen was repeated until the difference between two subsequent weight measurements was negligible. At that stage, the steady state moisture distribution was assumed to exist within the wood. After the last wet wood moisture profile was measured the specimens were oven dried at 103 ± 2 °C down to 0.005 equilibrium moisture content. During the drying process the specimens were weighed periodically and when no further change was detected drying was terminated. The dried specimens were then scanned with gamma ray densitometer to measure the radiation beam attenuation caused by the dry wood and plastic cup at the same locations where wet wood moisture profiles were taken before. Wood shrinkage due to drying, which altered the measured locations with respect to the datum (side drain hole), was taken into consideration with the assumption that local shrinkage was linearly distributed.

After the dry specimens were scanned and their physical properties such as weight and dimensions were measured, these data were also stored on the same tape. A total of eighteen specimens were tested; twelve for tangential permeability and six for longitudinal permeability. At each set of experiment, six specimens were tested simultaneously. The two experiment sets for tangential permeability, first 12 samples, required about 45 and 50 days for completion of each set consecutively, and the longitudinal permeability experiment, last six samples, required about 24 days for completion. The first set had nine wet scans and one dry scan. The second set had ten wet scans and one dry scan, and the final set (longitudinal permeability) had twelve wet scans and one dry scan.

The errors introduced into the measured quantities due to equipment and procedure were dealt with through an uncertainty analysis (appendix A). To provide sample results specimen number three was used (appendix B). Some intermediate results of data reduction are presented in appendices C and D, and the final unsaturated permeability results for sample number three is presented in appendix E.

Data reduction (sample data reduction in appendix F) was done on a micro computer (Commodore 64, computer codes in appendix G). With appropriate correction factors, local moisture contents and saturation levels along the specimens were calculated for different runs. Thus, the distributions of $S(Z,t)$ were calculated. From the steady state saturation profiles, the functional dependency of the capillary pressure on saturation $P_c(s)$ (Spolek, 1981b) was calculated for each specimen. Then utilizing numerical integration and differentiation for equation (27), the permeability as a function of saturation $k(s)$ was evaluated for both tangential and longitudinal permeability.

CHAPTER V

RESULTS AND DISCUSSION

Intermediate and final results will be presented in addition to a discussion of curve fitting techniques utilized in calculation. Figures 10 to 27 present saturation versus location profiles for wood samples. Each profile in a plot represents local saturations at the end of a centrifuge spinning period. Figure 9 indicates the order in which the profiles in Figure 10 to 27 correspond with spinning periods. First profile (scan TIME 00) in each plot is for the beginning of experiment and last profile (e.g. scan time 08 for first six samples) present the local saturations after the last spinning period. As it is evident from saturation versus location plots at wood locations furthest away from the saturated end (at $Z = 0$ cm a full saturation was maintained during experiment), there is a trend of saturation depletion as spinning time (accumulated spinning durations) increases, while the saturation of the other end remains relatively unchanged regardless of spinning time. The specimen behavior at the saturated end is expected because the capillary forces are sufficient to maintain a liquid column about two centimeters in height (Spolek, 1984).

The abrupt variation in saturation in adjacent points as is indicated in saturation versus location plots is caused by two major factors. The first factor is the inhomogeneity of wood itself. There

Scan Times 00,01,02,... are:

Samples 1 to 6

0;.75;1.75;3.9;6.75;10.75;18.75;
25.85;45.75 days

samples 7 to 12

0;.75;1.75;2.75;3.75;5.75;5;13.9;
25;44.9 days

samples 13 to 18

0;.95;2.05;3.55;4.9;5.95;9.8;
12.75;.85;3.9;6.85;11.2 days

Z Locations Z¹,Z²,... are:

.2024;.60552;1.012;1.4168;1.8216;
2.2264;2.6312;3.036;3.4408;3.8456;
4.2504;4.6552;5.06;5.4648;5.8696;
6.2744;6.6792;7.084;7.4888;7.8936 CM

· :TIME 00
✓ :TIME 01
Δ :TIME 02
▽ :TIME 03
◇ :TIME 04
+ :TIME 05
X :TIME 06
★ :TIME 07
Λ :TIME 08
κ :TIME 09
:TIME 10
○ :TIME 11

Figure 9. Legend for figures 10 to 27.

Figure 10. Saturation vs. location, sample #1.

Figure 11. Saturation vs. location, sample #2.

Figure 12. Saturation vs. location, sample #3.

Figure 13. Saturation vs. location, sample #4.

Figure 14. Saturation vs. location, sample #5.

Figure 15. Saturation vs. location, sample #6.

Figure 16. Saturation vs. location, sample #7.

Figure 17. Saturation vs. location, sample #8.

Figure 18. Saturation vs. location, sample #9.

Figure 19. Saturation vs. location, sample #10.

Figure 20. Saturation vs. location, sample #11.

Figure 21. Saturation vs. location, sample #12.

Figure 22. Saturation vs. location, sample #13.

Figure 23. Saturation vs. location, sample #14.

Figure 24. Saturation vs. location, sample #15.

Figure 25. Saturation vs. location, sample #16.

Figure 26. Saturation vs. location, sample #17.

Figure 27. Saturation vs. location, sample #18.

are biological variations within wood in terms of local wood density, cell structure and cell orientation. Beside these inherent inhomogeneities, cracks develop in wood due to drying. In calculating local moisture content and consequently the saturation levels dry wood gamma radiation scans were used (refer to appendix F, Sample Data Reduction). Wherever a scan is done through a crack (due to increase of gamma counts) a false higher saturation level is calculated. The bad saturation level data points due to cracks were detected by statistical methods (refer to appendix F) and corrected. However, not much could be done for general inhomogeneous characteristics of the wood sample. To calculate saturation levels, local wood density and fiber saturation point (FSP) were required. The author had to assume an overall uniform density and FSP (appendix F) and accept the resulting saturation fluctuations. Since the solution of equation (27) requires the gradient of saturation profile, a least square curve fit was used to smooth out local fluctuations in order to avoid differentiation of actual data. Since a trend of descending saturation levels from $Z = 0$ cm to $Z = L$ was expected a power equation curve fit was used (Figures 28 and 29). With each curve fit the corresponding correlation coefficient was also calculated as a measure of its goodness of fit. In most cases curve fits showed to be very good representatives of actual data. Nevertheless, one should bear in mind that curve fits do not alter the actual fluctuating nature of data, which is of concern.

Figures 30 and 31 represent typical functional dependence of capillary pressure on saturation. Experimental results presented in these figures indicate this dependence as expected (Spolek, 1981b; Collins, 1961), with increasing capillary pressure as the saturation

Figure 28. Curve fit results for S vs. Z, sample #3.

Figure 29. Curve fit results for S vs. Z, sample #5.

Figure 30. P_c vs. S data point, sample #3.

Figure 31. P_c vs. S data points, sample #5.

decreases. Since the gradient of this curve (capillary pressure versus saturation) is also needed for solution of equation (27), a least square curve fit was used to fit a power equation onto the data points. Again the power equation curve fit was used to ensure that the curves had a negative slope all through the desired range to meet the expected trend of increasing capillary pressure with reducing saturation level. For the data points the capillary pressures (refer to appendix F for calculation) were plotted against the final saturation profile for each sample. Figure 32 and 33 represent typical curve fit results.

For all curve fits, S vs. Z and P_c vs. S , two major criteria were considered. First, the data points which corresponded to crack locations on wood samples were not used (these points were statistically singled out, refer to appendix F). In addition to elimination of "crack" data points some other data points (very few, 12 points out of a total of 3720 points) that seemed to be bad data points caused by bad wet wood gamma radiation scans were corrected. For a list of eliminated and corrected data points reader is referred to appendix F. The other criterion was selecting a range for the data points used in curve fits for different samples. Initially, saturation versus location curves were observed; based on that, suitable ranges of location within which the corresponding section of curves indicated a "power equation curve" trend were picked for each sample. Next, the plots of capillary pressure versus saturation were studied for each sample; if they showed the same "power equation curve" trend within the selected range then the range was used for curve fits, otherwise the data range was corrected to get the proper trend for the P_c vs. S curve. Table I summarizes the location ranges used for each sample. Note that each sample is divided

Figure 32. Curve fit results for P_c vs. S , sample #3.

Figure 33. Curve fit results for P_c vs. S , sample #5.

into 20 scan locations Z_0 to Z_{20} where Z_0 is at 0.2024 cm and location intervals are $\Delta Z = 0.4048$ cm.

Table II
RANGE OF LOCATION Z_i FOR CURVE FITS

Sample #	Range of i	#	Range of i	#	Range of i	#	Range of i
1	4-20	6	7-20	11	2-18	16	5-13
2	4-18	7	4-15	12	3-18	17	4-16
3	1-20	8	6-15	13	7-20	18	7-20
4	11-20	9	1-20	14	7-13		
5	7-19	10	4-20	15	5-14		

Equation (27) results in permeability at the local saturation a distance L from the base of the specimen. At different runs as centrifuge times increase and (L) location saturation $S(L)$ changes, the permeability subsequently changes. Considering the form of equation (27) one expects that by reducing the upper range location (L) in calculations the results yield new permeability values at new saturation levels, thus increasing the number of data points representing permeability as a function of saturation. However, as it will be discussed later, through reducing the upper range location (L) higher saturations $S(L)$ resulted but computed $k(S(L))$ permeabilities indicated a decreasing trend which is contrary to the general phenomenon that higher saturation level in a porous media will cause higher permeability properties. This behavior in calculated unsaturated permeabilities is due to sensitivity of the equation (27) to the calculating gradients of saturation and capillary pressure.

The remaining variables in equation (27) were estimated based on data available in literature (i.e. water viscosity, wood porosity, saturated permeability value). The fully saturated permeability for each wood sample proved to be the most difficult to estimate. Comstock (1970) provides a range of values for saturated permeability of Southern Pine. However, in order to correctly calculate the unsaturated permeability of a wood sample, one needs to know the sample's correct saturated permeability value. Values of $k(\text{sat.})$ in the range provided by Comstock (1970) were used as a parameter. The unsaturated permeability results calculated with the $k(\text{sat.})$ range provided by Comstock (1970) showed a functional dependence on $k(\text{sat.})$ for tangential permeability, however such dependence was not shown in the case of longitudinal permeability.

Results of two other studies (Tesoro, 1974; Spolek, 1981b) which provide values for unsaturated permeability are compared with tangential permeability results in this study, Figure 34. Mechanistic model predicted permeability (Spolek, 1981b) is based on mathematical modeling, and experimentally predicted permeability (Tesoro, 1974) is based on two phase fluid flow. It seems that current study results indicate that wood behavior tends to comply with the mechanistic model.

Figures 35 to 44 are representative samples of unsaturated permeability results obtained in this study. These figures plot relative permeability values (ratio of unsaturated permeability to saturated permeability) against saturation levels. The acceptable range for both axis are 0 to 1. Each point on the " $k(s)/k(\text{sat.})$ vs. S " plots refers to an experiment run with a specific $k(\text{sat.})$ value. For example, for the first six samples, since there was eight centrifuge runs (and

Figure 34. Unsaturated permeability results comparison.

nine gamma scans), the figure for sample 2 (Figure 35) has eight data points for each $k(\text{sat.})$ value. The range of $k(\text{sat.})$ used for the plots was based on the range suggested by Comstock (1970). For tangential permeability range is 0.5×10^{-4} to 3×10^{-4} Darcy, and for longitudinal permeability range is .039 to 2.15 Darcy. As it is indicated on Figures 35 to 44, $k(s)/k(\text{sat.})$ values range from -4 to 1.4 for tangential permeability and up to 8 for longitudinal permeability. Whereas as mentioned before, the acceptable range is only 0 to 1. This is an indication of the sensitivity of equation (27) to the gradients terms that are used to calculate $k(s(L))$. The procedure utilized to measure local time dependent saturation levels of wood samples (gamma radiation densitometer) yields accurate results with less than 5% relative error (refer to appendix A, Uncertainty Analysis). However, it seems impractical to calculate unsaturated permeability of wood with this method. The uncertainty analysis presented in appendix A indicates that using equation (27) will result in $k(s(L))$ values with about 112% relative error (with 95% confidence interval) despite low relative errors in saturation. Because of the inhomogeneous nature of wood, a high degree of fluctuation is observed in measured local, time dependent saturation levels. These fluctuations affect the gradient terms in equation (27) through their corresponding curve fit results. The result of wood inhomogeneity is well observed in the uncertainty results of $k(S(L))$.

Although the calculated unsaturated permeabilities as single data points can not be used to generate any functional dependency of permeability versus saturation, the total results for each wood sample indicates some general trends. It can be seen that for tangential

Figure 36. Relative permeability vs. saturation, sample #3.

Figure 37. Relative permeability vs. saturation, sample #3, acceptable range of permeability results.

Figure 38. Relative permeability vs. saturation, sample #4.

Figure 39. Relative permeability vs. saturation, sample #5.

Figure 40. Relative permeability vs. saturation, sample #9.

Figure 41. Relative permeability vs. saturation, sample #15, partial result presentation.

Figure 42. Relative permeability vs. saturation, sample #15, total result presentation.

Figure 43. Relative permeability vs. saturation, sample #17, partial result presentation.

Figure 44. Relative permeability vs. saturation, sample #17, total result presentation.

permeability plots (Figures 35 to 40), a general trend is demonstrated that indicates the relative permeability values increase with an increase in the assumed value for saturated permeability values (positive trend). This trend is better shown in Figures 45 to 49. Each line on these plots refers to a specific experiment run used to calculate unsaturated permeability at various saturated permeability values. Figures for samples #2 (RUN 6) and sample #5 (RUN 6) indicate that some runs demonstrate a behavior contrary to what the author refers to as a positive trend. However, from a total of 102 runs, 85 runs indicated positive trend (83.3%) and 17 indicated a negative trend (16.7%). In any case, when the calculated results are studied as a whole for tangential permeability one can result that calculated unsaturated permeability is a function of saturated permeability. This behavior is not observed in the results for longitudinal permeability samples Figures 50 and 51; it seems that calculated unsaturated permeabilities are not dependent on saturated permeabilities in this case. This lack of sensitivity of unsaturated permeability results to assumed values for saturated permeability values indicates that in equation (27) the denominator (flow inducing pressure gradient at the end of sample $Z = L$) and the integral part (the term representing moisture drainage) are dominant in terms of order of magnitude over the term (pressure gradient at $Z = 0$) including the saturated permeability value.

As is shown in appendix F, Sample Data Reduction, to calculate the gradients in equation (27) the curve fit values for data points are used. If measured data points show a slightly more convex form, although the overall representation of actual saturation profile in wood

Figure 45. Relative permeability vs. saturated permeability, sample #2.

Figure 46. Relative permeability vs. saturated permeability, sample #3.

Figure 47. Relative permeability vs. saturated permeability, sample #4.

Figure 48. Relative permeability vs. saturated permeability, sample #5.

Figure 49. Relative permeability vs. saturated permeability, sample #9.

Figure 50. Relative permeability vs. saturated permeability, sample #15.

Figure 51. Relative permeability vs. saturated permeability, sample #17.

sample is still accurate, the slopes of their curves are affected to an extent that will affect the final results of $k(S(L))$. This is a major cause that invalidates the method of this study for calculating unsaturated permeability, and also prevents one from altering the range of limits on the integration (which resulted in equation (27)) in order to obtain more data points representing $k(s(L))$.

In order to get a general idea what the whole study resulted in, Figures 52 and 53 show the results of " $k(s)/k(\text{sat.})$ vs. S " for all tangential permeability wood samples for saturated permeability value of 2×10^{-4} Darcy (mid-range as suggested by Comstock (1970)). Studying Figure 53 indicates that at saturation levels down to 50% still permeability does not drop to zero. This supports the mechanistic model for wood behavior which is presented by Spolek (1981a). Figure 34 presented the correspondence between results of this study and mechanistic model.

Figure 52. Tangential permeability results.

Figure 53. Tangential permeability results, acceptable range presentation.

SUMMARY AND CONCLUSION

The intent of this study was to develop a practical and scientific procedure for determining the unsaturated liquid permeability of wood using transient flow method. The procedure consists of inducing liquid drainage from wood and then through utilization of noninvasive measurement methods, saturation profiles along wood are measured. With the liquid flow data and saturation profiles, unsaturated permeability is back calculated from the liquid phase continuity equation. The transient flow is a far better representation of fluid flow through wood during drying processes than steady state single fluid or mixed fluids (gas and liquid) flow methods utilized up to present. Results of this study based on saturated permeability values generated through a steady state flow study by Comstock (1970) show some strong indications that a mechanistic flow model based on mathematical modeling (Spolek, 1981b) can describe fluid flow through wood. However, the number of data points generated in this study and the uncertainty level associated with them is insufficient to confirm the accuracy of the mechanistic model. Although the experimentation part of the study, which resulted in values for local time dependent saturation levels along the wood samples, proved to be adequately accurate (with less than 5% relative error) the final results for unsaturated permeability values proved to have high level of uncertainty (112% relative error). The high level of uncertainty in the final results can be attributed to the local fluctuation in data which is caused by the natural inhomogeneities in wood. Additional testing for unsaturated permeability while performed along with saturated permeability measurements for similar wood samples will provide more accurate results which can be used to provide

representative data averages. In conclusion, this study confirmed the validity and reliability of experimentation procedure and provided more backing for mechanistic based predictive model for fluid flow through wood in tangential direction (Spolek, 1981b).

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APPENDIX A

UNCERTAINTY ANALYSIS

UNCERTAINTY ANALYSIS

Following is an uncertainty analysis for measured saturation levels and calculated unsaturated permeability based on Kline and McClintock theories (Kline, 1953). The experimental data used for this analysis is from wood sample number three which was tested for tangential permeability. A 95% confidence interval (20:1 odds) is assumed throughout the analysis. Starting with governing equation (27) we have:

$$k(S(L)) = \frac{k(S(0)) [C(S(0)) \cdot S'(0) - B(0)] - \mu \phi \int_0^L \left(\frac{\partial S}{\partial t} \right) dz}{C(S(L)) \cdot S'(L) - B(L)} \quad (U1)$$

$$\text{since} \quad C(S(z)) \cdot S'(z) = \frac{\partial P_c}{\partial S} \cdot \frac{\partial S}{\partial z} = \frac{dP_c}{dz} \quad (U2)$$

we have:

$$k(S(L)) = \frac{k(S(0)) \left[\frac{dP_c}{dz} \Big|_{z_0} - B(0) \right] - \mu \phi \int_0^L \left(\frac{\partial S}{\partial t} \right) dz}{\frac{dP_c}{dz} \Big|_{z_L} - B(L)} \quad (U3)$$

where

$$B(Z) = \rho_l \omega^2 (R-Z) \quad (U4)$$

$$P_c = \rho_l \omega^2 Z (R-Z/2) \quad (\text{at steady state conditions}) \quad (U5)$$

$$\int \frac{\partial S}{\partial t} dz = \frac{\Delta Z}{\Delta t} \left[\sum_{i=1}^{20} S_{z_i} \Big|_{t_2} - \sum_{i=1}^{20} S_{z_i} \Big|_{t_1} \right] = \frac{\Delta Z}{\Delta t} \cdot n \cdot [S_{ave} \Big|_{t_2} - S_{ave} \Big|_{t_1}] \quad (U6)$$

In equation (U3) saturation term can be singled out for individual uncertainty analysis because it has no common factor with other terms in equation (U3).

$$S = \frac{M-FSP}{M_{max}-FSP} = \frac{M-FSP}{\Delta M} \quad (U7)$$

$$M = \frac{-V_{wd+w}}{V_{wd}} \cdot \frac{1}{\mu_w \rho_{wd} L_{wd+w}} \left[\ln \frac{N_{wd+w}}{N_{wd}} + \rho_{wd} \mu_{wd} (L_{wd+w} - L_{wd}) \right] \quad (U8)$$

(Spolek, 1981a)

$$N = \frac{1}{1/N - \tau} \quad (U9)$$

where N = gamma counts

τ = instrument dead time (gamma ray densitometer)

$$N_{wd} = N_{wd+EMC} \times \exp(\mu_{wd} \cdot \rho_{wd} \cdot L_{wd} \cdot EMC)$$

$$\rho_{measured} = \frac{m_{wd+EMC}}{V_{wd+EMC}} \quad (U10)$$

$$\rho_{wd} = \frac{\rho_{measured}}{1+EMC(V_{wd}/V_{wd+EMC})} \quad (U11)$$

Therefore:

$$S = \frac{1}{\Delta M} \times \left\{ \frac{-V_{wd+w}}{V_{wd}} \cdot \frac{1}{\mu_{wd} \cdot L_{wd} \cdot \left[\frac{m_{wd+EMC}}{V_{wd+EMC}} \cdot \frac{1}{1+EMC(V_{wd}/V_{wd+EMC})} \right]} \times \right.$$

$$\left. \left[\ln \frac{1}{1/N_{wd+w} - \tau} \right. \right.$$

$$\left. \left(\frac{1}{1/N_{wd+EMC} - \tau} \right) \exp(\mu_{wd} \cdot \frac{m_{wd+EMC}}{V_{wd+EMC}} \cdot \frac{1}{1+EMC(V_{wd}/V_{wd+EMC})} \cdot L_{wd} \cdot EMC) \right.$$

$$\left. \frac{m_{wd+EMC}}{V_{wd+EMC}} \cdot \frac{1}{1+EMC(V_{wd}/V_{wd+EMC})} \cdot \mu_{wd} (L_{wd+w} - L_{wd}) \right] - FSP \} \quad (U12)$$

Assume: (for values refer to appendix F)

a₁; $(V_{wd}/V_{wd+EMC}) = 1$ with no error involved.

a₂; no error in $EMC = 0.005$

a₃; a₁ and a₂ result in $\Delta \rho = f(\Delta m, \Delta V_{wd})$

a₄; no error in $\mu_{wd} = 0.189 \text{ cm}^2/\text{gm}$

a₅; no error in $\mu_w = 0.201 \text{ cm}^2/\text{gm}$

a₆; no error in FSP = 0.3

a₇; no error in $\Delta M = 1.86$

a₈; no error in τ (instrument dead time), $\tau = 10^{-7}$ seconds/count

a₉; $V_{wd} = V_{wd+EMC}$

$$S = \frac{1}{1.86} \times \left\{ \frac{-V_{wd+w}}{V_{wd}} \cdot \frac{1}{0.2 \times L_{wd+w} \cdot \frac{M_{wd+EMC}}{V_{wd+EMC}}} \cdot \frac{1}{\ln \frac{1/N_{wd+w}^{-8 \times 10^{-7}}}{1/N_{wd+EMC}^{-8 \times 10^{-7}} \exp(.001 \times L_{wd} \times \frac{M_{wd+EMC}}{V_{wd+EMC}})}} + 0.188 \times \frac{M_{wd+EMC}}{V_{wd+EMC}} (L_{wd+w} - L_{wd}) \right\} - 0.3 \quad (U13)$$

Assume:

a₁₀; Sample dimensions are $E \times F \times L$ (Figure 54) with $(wd+w)$ and (wd) subscripts referring to (wet wood) and (dry wood) respectively, where F corresponds with same direction as Z along the sample length, and L corresponds with radiation absorption length.

a₁₁; In measurements Z_0 , Z_L and ΔZ are treated as separate measurement from overall dimension measurements.

$$k(S(L)) = \frac{k(S(0)) \left[\frac{dP}{dZ} \Big|_{Z_0} - B(0) \right] - \mu_0 \cdot n \cdot \frac{\Delta Z}{\Delta t} [S_{ave} \Big|_{t_{i+1}} - S_{ave} \Big|_{t_i}]}{\frac{dP}{dZ} \Big|_{Z_L} - B(L)} \quad (U14)$$

Here n = number of scanned locations between Z_0 and Z_L .

Figure 54. Wood sample typical dimensions.

Note: The uncertainty analysis will be done for sample #3 with a location range of $Z_0 = 0.2024$ cm to $Z_L = 7.8936$ cm and $n = 20$ for $k(S(L))$.

Since there is no common variable between parameters used to calculate S (saturation) and other terms used in calculating $k(S(L))$, the uncertainty of S is calculated separately.

As an average representative set of values scan times 03 and 04 are used.

$$V_{wd+w} = E_{wd+w} \times F_{wd+w} \times L_{wd+w} \quad (U15)$$

$$V_{wd} = E_{wd} \times F_{wd} \times L_{wd} \quad (U16)$$

Applying equations (U15) and (U16) to (U13) will result in:

$$S = \frac{1}{1.86} \left\{ \frac{-E_{wd+w} \times F_{wd+w}}{.2 \times m_{wd+EMC}} \times \left[\ln \frac{1/N_{wd+EMC} - 8 \times 10^{-7}}{(1/N_{wd+w} - 8 \times 10^{-7}) \cdot \exp(0.001 \times \frac{m_{wd+EMC}}{E_{wd} \times F_{wd}})} \right] + 0.188 \times \frac{m_{wd+EMC} (L_{wd+w} - L_{wd})}{E_{wd} \times F_{wd} \times L_{wd}} \right\} - 0.3 \quad (U17)$$

To determine the effect of the term $\exp(\mu_{wd} \cdot \rho_{wd} \cdot L_{wd} \cdot EMC)$, equation (U10), on uncertainty in S , its uncertainty is analyzed separately.

$$\exp(\mu_{wd} \cdot \rho_{wd} \cdot L_{wd} \cdot EMC) = \exp\left(.001 \times \frac{m_{wd+EMC}}{E_{wd} \times F_{wd}}\right) = D \quad (U18)$$

$$\Delta D = \left[\left(\frac{\partial D}{\partial m_{wd+EMC}} \cdot \Delta m_{wd+EMC} \right)^2 + \left(\frac{\partial D}{\partial E_{wd}} \cdot \Delta E_{wd} \right)^2 + \left(\frac{\partial D}{\partial F_{wd}} \cdot \Delta F_{wd} \right)^2 \right]^{1/2} \quad (U19)$$

$$\frac{\partial D}{\partial m_{wd+EMC}} = \left[\exp\left(.001 \times \frac{m_{wd+EMC}}{E_{wd} \times F_{wd}}\right) \right] \times \frac{0.001}{E_{wd} \times F_{wd}} \quad (U20)$$

$$\frac{\partial D}{\partial E_{wd}} = \left[\exp\left(.001 \times \frac{m_{wd+EMC}}{E_{wd} \times F_{wd}}\right) \right] \times \frac{-0.001 \times m_{wd+EMC}}{E_{wd}^2 \times F_{wd}} \quad (U21)$$

$$\frac{\partial D}{\partial F_{wd}} = \left[\exp \left(.001 \times \frac{m_{wd+EMC}}{E_{wd} \times F_{wd}} \right) \right] \times \frac{-0.001 \times m_{wd+EMC}}{E_{wd} \times F_{wd}^2} \quad (U22)$$

with

$$m_{wd+EMC} = 75 \pm 0.5 \text{ gm}$$

$$E_{wd} = 5.047 \pm .1 \text{ cm}$$

$$F_{wd} = 8.573 \pm .1 \text{ cm}$$

we will have

$$\Delta D = 0.024 \text{ and } D = 1.002$$

since $\frac{\Delta D}{D} = 0.024 = 2.4\%$, and $D \approx 1$ is used as a correction factor for N_{wd+EMC} , we assume the error that D (exponential correcting factor) introduces is negligible and it does not affect the error introduced in the final result of unsaturated permeability.

Thus we have:

$$S = \frac{1}{1.86} \left\{ \frac{-E_{wd+w} \times F_{wd+w}}{.2 \times m_{wd+EMC}} \times \left[\ln \frac{1/N_{wd+EMC}^{-8 \times 10^{-7}}}{(1/N_{wd+w}^{-8 \times 10^{-7}}) \times 1.002} + 0.188 \times \frac{m_{wd+EMC} (L_{wd+w} - L_{wd})}{E_{wd} \times F_{wd} \times L_{wd}} \right] - .3 \right\} \quad (U23)$$

and

$$\begin{aligned} \Delta S = & \left[\left(\frac{\partial S}{\partial E_{wd+w}} \cdot \Delta E_{wd+w} \right)^2 + \left(\frac{\partial S}{\partial F_{wd+w}} \cdot \Delta F_{wd+w} \right)^2 + \left(\frac{\partial S}{\partial L_{wd+w}} \cdot \Delta L_{wd+w} \right)^2 + \right. \\ & \left(\frac{\partial S}{\partial E_{wd}} \cdot \Delta E_{wd} \right)^2 + \left(\frac{\partial S}{\partial F_{wd}} \cdot \Delta F_{wd} \right)^2 + \left(\frac{\partial S}{\partial L_{wd}} \cdot \Delta L_{wd} \right)^2 + \left(\frac{\partial S}{\partial m_{wd+EMC}} \cdot \Delta m_{wd+EMC} \right)^2 + \\ & \left. \left(\frac{\partial S}{\partial N_{wd+EMC}} \cdot \Delta N_{wd+EMC} \right)^2 + \left(\frac{\partial S}{\partial N_{wd+w}} \cdot \Delta N_{wd+w} \right)^2 \right]^{1/2} \quad (U24) \end{aligned}$$

let

$$\beta = \ln \frac{1/N_{wd+EMC} - 8 \times 10^{-7}}{(1/N_{wd+w} - 8 \times 10^{-7}) \times 1.002} \quad (U25)$$

then:

$$S = \frac{1}{1.86} \left\{ \frac{-\beta \times E_{wd+w} \times F_{wd+w}}{.2 \times m_{wd+EMC}} - .94 \times \frac{E_{wd+w} \times F_{wd+w} (L_{wd+w} - L_{wd})}{E_{wd} \times F_{wd} \times L_{wd}} - .3 \right\} \quad (U26)$$

and

$$\frac{\partial S}{\partial E_{wd+w}} = \frac{1}{1.86} \left\{ \frac{\beta \times F_{wd+w}}{.2 \times m_{wd+EMC}} - .94 \times \frac{F_{wd+w} (L_{wd+w} - L_{wd})}{E_{wd} \times F_{wd} \times L_{wd}} \right\} \quad (U27)$$

$$\frac{\partial S}{\partial F_{wd+w}} = \frac{1}{1.86} \left\{ \frac{\beta \times E_{wd+w}}{.2 \times m_{wd+EMC}} - .94 \times \frac{E_{wd+w} (L_{wd+w} - L_{wd})}{E_{wd} \times F_{wd} \times L_{wd}} \right\} \quad (U28)$$

$$\frac{\partial S}{\partial L_{wd+w}} = \frac{1}{1.86} \left\{ -.94 \times \frac{E_{wd+w} \times F_{wd+w}}{E_{wd} \times F_{wd} \times L_{wd}} \right\} \quad (U29)$$

$$\frac{\partial S}{\partial E_{wd}} = \frac{1}{1.86} \left\{ .94 \times \frac{E_{wd+w} \times F_{wd+w} (L_{wd+w} - L_{wd})}{F_{wd} \times L_{wd} \times E_{wd}^2} \right\} \quad (U30)$$

$$\frac{\partial S}{\partial F_{wd}} = \frac{1}{1.86} \left\{ .94 \times \frac{E_{wd+w} \times F_{wd+w} (L_{wd+w} - L_{wd})}{E_{wd} \times L_{wd} \times F_{wd}^2} \right\} \quad (U31)$$

$$\frac{\partial S}{\partial L_{wd}} = \frac{1}{1.86} \left\{ -.94 \times \frac{E_{wd+w} \times F_{wd+w}}{E_{wd} \times F_{wd}} \cdot \frac{-L_{wd+w}}{L_{wd}^2} \right\} \quad (U32)$$

$$\frac{\partial S}{\partial m_{wd+EMC}} = \frac{1}{1.86} \left\{ \frac{\beta \times E_{wd+w} \times F_{wd+w}}{.2 (m_{wd+EMC})^2} \right\} \quad (U33)$$

$$\frac{\partial S}{\partial N_{wd+EMC}} = \frac{1}{1.86} \left[\frac{E_{wd+w} \times F_{wd+w}}{.2 \times m_{wd+EMC}} \right] \times \frac{(1/N_{wd+EMC}^2) \times 1.002}{1/N_{wd+EMC} - 8 \times 10^{-7}} \quad (U34)$$

$$\frac{\partial S}{\partial N_{wd+w}} = \frac{-1}{1.86} \left[\frac{E_{wd+w} \times F_{wd+w}}{.2 \times m_{wd+EMC}} \right] \times \frac{1/N_{wd+w}^2}{1/N_{wd+w} - 8 \times 10^{-7}} \quad (U35)$$

In calculating the error involved in measuring gamma counts N , since gamma emissions have poisson distribution of intensity, the standard deviation of N is $S_n = N^{1/2}$. For a 95% confidence interval:

$$\Delta N = 2S_n = 2N^{1/2} \quad (\text{U36})$$

Therefore:

$$\Delta N_{wd+w} = 2N_{wd+w}^{1/2} \quad (\text{U37})$$

$$\Delta N_{wd+EMC} = 2N_{wd+EMC}^{1/2} \quad (\text{U38})$$

Assuming on average (for sample #3, scan times 03 and 04).

$$E_{wd+w} = 5.065 \pm .1 \text{ cm} \quad , \quad E_{wd} = 5.047 \pm .1 \text{ cm}$$

$$F_{wd+w} = 8.956 \pm .1 \text{ cm} \quad , \quad F_{wd} = 8.573 \pm .1 \text{ cm}$$

$$L_{wd+w} = 4.483 \pm .1 \text{ cm} \quad , \quad L_{wd} = 4.341 \pm .1 \text{ cm}$$

$$m_{wd+EMC} = 75 \pm .5 \text{ gm}$$

$$N_{wd+w} = 5 \times 10^4 \pm 447 \text{ counts}$$

$$N_{wd+EMC} = 9 \times 10^4 \pm 600 \text{ counts}$$

Evaluating equation (U24) we have:

$$\Delta S = 0.03503 \approx 0.035 \quad (\text{U39})$$

for an average saturation of $S = 0.7459$

$$\text{Thus } \frac{\Delta S}{S} = 4.69\% \quad (\text{U40})$$

Calculating the uncertainty for maximum and minimum values of saturation will result in:

Sample #3, location Z_1 at scan time 00 we have:

$$S_{\max} = 1.015$$

$$N_{\text{wd+EMC}} = 94586 \pm 615 \text{ counts}$$

$$N_{\text{wd+w}} = 47252 \pm 434 \text{ counts}$$

Sample #3, location Z_{20} at scan time 08 we have:

$$S_{\min} = .383$$

$$N_{\text{wd+EMC}} = 87973 \pm 593 \text{ counts}$$

$$N_{\text{wd+w}} = 63655 \pm 504 \text{ counts}$$

Calculating equation (U24) , the following table will result.

Table III
SATURATION UNCERTAINTY VALUES

	S	ΔS	$\frac{\Delta S}{S}$
Min. Saturation	0.383	0.0283	7.38%
Average Saturation	0.7459	0.03503	4.69%
Max Saturation	1.015	0.0382	3.76%

Calculating the uncertainty in calculated unsaturated permeability $k(S(L))$ proved to be practically impossible through an analytical method. This was mainly due to the fact that for the gradient parts $\frac{\partial P}{\partial S}$ and $\frac{\partial S}{\partial Z}$ values of curve fits were used. Therefore, the best possible method for calculating the uncertainty of $k(S(L))$ seemed to be through actual numerical calculation. All the parameters involved in calculating $k(S(L))$ were perturbed randomly and $k(S(L))$ was calculated.

This was repeated 51 times and through statistical analysis the uncertainty in $k(S(L))$ was calculated. Following is a detailed description of perturbation procedures utilized.

Since the uncertainty of saturation levels was calculated, the perturbation was done on saturation level and other parameters in the process of calculating $k(S(L))$. The values (averages) and their corresponding uncertainty levels used in calculation were:

$\Delta S = 0.03503$ (uncertainty in saturation), for S values refer to appendix C.

$Z_0 = 0.2024 \pm 0.1$ cm

$Z_L = 7.8936 \pm 0.1$ cm

$\Delta Z = 0.4048 \pm 0.01$ cm (integration interval)

$\omega = 500 \pm 20$ rpm

$\Delta t = 30$ seconds (uncertainty in time measurement) for t values refer to appendix F

51 curve fit values for $P_c(S)$ and $S(Z)$ were calculated with perturbed parameter and then their values (for gradient terms in equation (U1)) along with other perturbed parameter were used to calculate $k(S(L))'S$.

The variations enforced on parameters had to be of a random nature and since a normal distribution of errors had to be assumed, the random perturbation had to have a normal distribution. The computer used to perform the calculations was capable of generating a uniformly distributed random number between 0 and 1 (code: RND(1)). To generate a normally distributed random number the following codes were utilized:

```

y = 0.0
FOR I = 1 to 12
y = y + RND (1)
NEXT I
y = y - 6.0

```

Resulting variable y is a normally distributed random number with a range of $-6 < y < 6$, average of zero, and standard deviation of 1 (i.e. 95% of times y has a value between -2 and 2). A brief discussion for justifying the utilized algorithm will be presented at the end of this appendix.

Since a normal distribution for errors was assumed the uncertainties in each parameter was equal to twice its standard deviation value.

$$\text{Saturation} - S \pm \Delta S = S \pm 2\sigma_S$$

Therefore anytime during the calculations a parameter had to be perturbed, a random variable y was generated and multiplied by half the uncertainty of the parameter, or one standard deviation, and that was the amount of variation introduced to that parameter.

$$\text{Perturbed saturation} = S + (\sigma_S \times y) = S + \frac{\Delta S}{2} \times y$$

Sample #3 was used for calculating perturbed values of unsaturated permeability $k(S(L))$. Calculations were repeated 51 times and results of calculated $k(S(L))$ for the first four runs of the sample #3 (with end saturation levels $.692 \leq S(L) \leq .791$) are presented in Figures 55 to 58. Figures 59 to 62 present the histograms for same data. Following table summarizes the calculated results for relative permeability ($k(S)/k(\text{sat.})$). In this table "Best Estimate" stands for the values

Figure 55. Uncertainty analysis, 1st run, sample #3.

Figure 56. Uncertainty analysis, 2nd run, sample #3.

Figure 57. Uncertainty analysis, 3rd run, sample #3.

Figure 58. Uncertainty analysis, 4th run, sample #3.

Figure 59. Uncertainty analysis, 1st run, histogram.

Figure 60. Uncertainty analysis, 2nd run, histogram.

Figure 61. Uncertainty analysis, 3rd run, histogram.

Figure 62. Uncertainty analysis, 4th run, histogram.

calculated with no perturbation and "Mean" stands for the calculated average from the perturbed calculations.

TABLE IV
RELATIVE PERMEABILITY UNCERTAINTY VALUES

Run	Scan Time	k(S)/k(sat.) Best Estimate	k(S)/k(sat.) Mean	$\sigma k(S)/k(\text{sat.})$ Standard Deviation	Saturation Best Estimate
1	00+01	.2376	.246	.191	.791
2	01+02	.7219	.638	.308	.745
3	02+03	.7014	.634	.383	.719
4	03+04	.6108	.587	.351	.692

Using the results for the four runs to get an average standard deviation for the relative permeability ($k(S)/k(\text{sat.})$) we have:

$$\sigma_{\text{ave}} = \left[\left(\sum_{i=1}^4 \sigma_i^2 \right) / 4 \right]^{1/2} = 0.3167$$

since we have assumed normal distribution we have:

$$\Delta(k(S)/K(\text{sat.})) = 2\sigma_{\text{ave}} = 0.6334$$

and relative error will be:

$$\frac{\Delta(k(S)/k(\text{sat.}))}{k(S)/k(\text{sat.})} = \frac{0.6334}{0.5679} = 112\%$$

In conclusion the results of this appendix indicate that for an average saturation value of 0.746 with a probability of 95% any measured saturation level is within $\pm 4.7\%$ of correct measured value, and any calculated unsaturated permeability value is within $\pm 112\%$ of correct calculated value.

DISCUSSION

Despite the low level of uncertainty in saturation levels a very high level of uncertainty is observed in final result of $k(S(L))$. This is due to the fact that for each gradient term in equation (U1) 20 saturation points are used to evaluate a curve fit and also the integration part in equation (U1) utilizes 40 saturation point. Altogether the errors in saturation levels effect $k(S(L))$ for 120 times. In addition to individual effect of saturation level errors, the fact that gradient of a set of data is much more sensitive to perturbation in a data point than the data points themselves indicate that high levels of uncertainty in $k(S(L))$ is not out of order.

Justification of algorithm used for generating normally distributed random numbers.

A uniform distribution with parameters α and β is presented as:

$$f(x) = \begin{cases} \frac{1}{\beta-\alpha} & \text{for } \alpha < x < \beta \\ 0 & \text{elsewhere} \end{cases}$$

Mean and variance of this distribution are (Miller, 1977)

$$\text{mean} = \bar{x} = \frac{\alpha + \beta}{2}$$

$$\text{variance} = \sigma^2 = \frac{1}{12} (\beta - \alpha)^2$$

For random numbers x between 0 and 1 we have

$$\bar{x} = \frac{0+1}{2} = .5$$

$$\sigma_x^2 = \frac{1}{12} (1-0)^2 = \frac{1}{12}$$

if variable y is such that

$$y = \left(\sum_{i=1}^{12} x_i \right) - 6 \text{ then } -6 < y < 6 \quad \text{where } 0 < x_i < 1.$$

and

$$\text{Mean } y = \bar{y} = \left(\sum_{i=1}^{12} .5 \right) - 6 = 6 - 6 = 0$$

and variances add up (note: subtracting constant 6 will not affect the variances).

$$\sigma_y^2 = \sum_{i=1}^{12} \sigma_x^2 = 12 \times \frac{1}{12} = 1$$

A theorem by Miller (1977) states that if a random variable has the value y and a distribution with the mean $\bar{y}$ and variance σ_y^2 , the corresponding normal standardized variable has the value $g = \frac{y - \bar{y}}{\sigma_y}$ and its distribution has zero mean and unit variance. Thus

$$g = \frac{y - 0}{1} = y$$

APPENDIX B

RAW DATA GAMMA COUNTS FOR SAMPLE #3

SAMPLE #3 INITIALIZATION DATA

READY.

SAMPLE # 3 INITIALIZATION DATA
DIMENSIONS ARE 8.956 X 5.065 X 4.483 CM
INITIAL NET MASS IS 473.5 GRAMS
WOOD ATTENUATION IS .189
WATER ATTENUATION IS .201
GAMMA ABSORPTION TIME IS 8E-06 SECONDS

SAMPLE #3 RAW DATA GAMMA COUNTS

SAMPLE # 3 RAW DATA GAMMA COUNTS

TIME IS : 0 DAYS

WOOD MASS IS : 473.5 GRAMS

POSITION(CM)= .2024 COUNTS= 47252
 POSITION(CM)= .6072 COUNTS= 48720
 POSITION(CM)= 1.012 COUNTS= 48853
 POSITION(CM)= 1.4168 COUNTS= 49080
 POSITION(CM)= 1.8216 COUNTS= 49666
 POSITION(CM)= 2.2264 COUNTS= 49397
 POSITION(CM)= 2.6312 COUNTS= 49686
 POSITION(CM)= 3.036 COUNTS= 49765
 POSITION(CM)= 3.4408 COUNTS= 49684
 POSITION(CM)= 3.8456 COUNTS= 49346
 POSITION(CM)= 4.2504 COUNTS= 48966
 POSITION(CM)= 4.6552 COUNTS= 49074
 POSITION(CM)= 5.06 COUNTS= 49006
 POSITION(CM)= 5.4648 COUNTS= 49960
 POSITION(CM)= 5.8696 COUNTS= 48524
 POSITION(CM)= 6.2744 COUNTS= 49863
 POSITION(CM)= 6.6792 COUNTS= 49486
 POSITION(CM)= 7.084 COUNTS= 49831
 POSITION(CM)= 7.4888 COUNTS= 50308
 POSITION(CM)= 7.8936 COUNTS= 50794

SAMPLE # 3 RAW DATA GAMMA COUNTS

TIME IS : .75 DAYS

WOOD MASS IS : 459.2 GRAMS

POSITION(CM)= .2024 COUNTS= 48239
 POSITION(CM)= .6072 COUNTS= 48558
 POSITION(CM)= 1.012 COUNTS= 52107
 POSITION(CM)= 1.4168 COUNTS= 52870
 POSITION(CM)= 1.8216 COUNTS= 52408
 POSITION(CM)= 2.2264 COUNTS= 52296
 POSITION(CM)= 2.6312 COUNTS= 52892
 POSITION(CM)= 3.036 COUNTS= 52857
 POSITION(CM)= 3.4408 COUNTS= 53343
 POSITION(CM)= 3.8456 COUNTS= 52347
 POSITION(CM)= 4.2504 COUNTS= 52010
 POSITION(CM)= 4.6552 COUNTS= 52036
 POSITION(CM)= 5.06 COUNTS= 50767
 POSITION(CM)= 5.4648 COUNTS= 51465
 POSITION(CM)= 5.8696 COUNTS= 50184
 POSITION(CM)= 6.2744 COUNTS= 50375
 POSITION(CM)= 6.6792 COUNTS= 51586
 POSITION(CM)= 7.084 COUNTS= 50398
 POSITION(CM)= 7.4888 COUNTS= 51926
 POSITION(CM)= 7.8936 COUNTS= 51375

SAMPLE # 3 RAW DATA GAMMA COUNTS

TIME IS : 1.75 DAYS

WOOD MASS IS : 456.8 GRAMS

POSITION(CM)= .2024 COUNTS= 48804
 POSITION(CM)= .6072 COUNTS= 48900
 POSITION(CM)= 1.012 COUNTS= 52465
 POSITION(CM)= 1.4168 COUNTS= 52791
 POSITION(CM)= 1.8216 COUNTS= 52191
 POSITION(CM)= 2.2264 COUNTS= 54301
 POSITION(CM)= 2.6312 COUNTS= 53694
 POSITION(CM)= 3.036 COUNTS= 55340
 POSITION(CM)= 3.4408 COUNTS= 53224
 POSITION(CM)= 3.8456 COUNTS= 53272
 POSITION(CM)= 4.2504 COUNTS= 53068

POSITION(CM)= 4.6552 COUNTS= 51846
 POSITION(CM)= 5.06 COUNTS= 52695
 POSITION(CM)= 5.4648 COUNTS= 51578
 POSITION(CM)= 5.8696 COUNTS= 50545
 POSITION(CM)= 6.2744 COUNTS= 52257
 POSITION(CM)= 6.6792 COUNTS= 51464
 POSITION(CM)= 7.084 COUNTS= 50705
 POSITION(CM)= 7.4888 COUNTS= 52141
 POSITION(CM)= 7.8936 COUNTS= 52693

SAMPLE # 3 RAW DATA GAMMA COUNTS

TIME IS : 3.9 DAYS

MOOD MASS IS : 452.5 GRAMS

POSITION(CM)= .2024 COUNTS= 48778
 POSITION(CM)= .6072 COUNTS= 48696
 POSITION(CM)= 1.012 COUNTS= 52663
 POSITION(CM)= 1.4168 COUNTS= 54056
 POSITION(CM)= 1.8216 COUNTS= 53295
 POSITION(CM)= 2.2264 COUNTS= 55066
 POSITION(CM)= 2.6312 COUNTS= 54972
 POSITION(CM)= 3.036 COUNTS= 55994
 POSITION(CM)= 3.4408 COUNTS= 54206
 POSITION(CM)= 3.8456 COUNTS= 53734
 POSITION(CM)= 4.2504 COUNTS= 53014
 POSITION(CM)= 4.6552 COUNTS= 52848
 POSITION(CM)= 5.06 COUNTS= 53509
 POSITION(CM)= 5.4648 COUNTS= 51855
 POSITION(CM)= 5.8696 COUNTS= 51423
 POSITION(CM)= 6.2744 COUNTS= 52550
 POSITION(CM)= 6.6792 COUNTS= 51585
 POSITION(CM)= 7.084 COUNTS= 51513
 POSITION(CM)= 7.4888 COUNTS= 53423
 POSITION(CM)= 7.8936 COUNTS= 53994

SAMPLE # 3 RAW DATA GAMMA COUNTS

TIME IS : 6.75 DAYS

MOOD MASS IS : 450.3 GRAMS

POSITION(CM)= .2024 COUNTS= 48294
 POSITION(CM)= .6072 COUNTS= 49124
 POSITION(CM)= 1.012 COUNTS= 53291
 POSITION(CM)= 1.4168 COUNTS= 54538
 POSITION(CM)= 1.8216 COUNTS= 53923
 POSITION(CM)= 2.2264 COUNTS= 54946
 POSITION(CM)= 2.6312 COUNTS= 54910
 POSITION(CM)= 3.036 COUNTS= 55705
 POSITION(CM)= 3.4408 COUNTS= 54642
 POSITION(CM)= 3.8456 COUNTS= 54890
 POSITION(CM)= 4.2504 COUNTS= 53420
 POSITION(CM)= 4.6552 COUNTS= 52657
 POSITION(CM)= 5.06 COUNTS= 54323
 POSITION(CM)= 5.4648 COUNTS= 52763
 POSITION(CM)= 5.8696 COUNTS= 52168
 POSITION(CM)= 6.2744 COUNTS= 53928
 POSITION(CM)= 6.6792 COUNTS= 51866
 POSITION(CM)= 7.084 COUNTS= 53062
 POSITION(CM)= 7.4888 COUNTS= 55381
 POSITION(CM)= 7.8936 COUNTS= 54560

SAMPLE # 3 RAW DATA GAMMA COUNTS

TIME IS : 10.75 DAYS

MOOD MASS IS : 449.8 GRAMS

POSITION(CM)= .2024 COUNTS= 48250
 POSITION(CM)= .6072 COUNTS= 48562
 POSITION(CM)= 1.012 COUNTS= 52747
 POSITION(CM)= 1.4168 COUNTS= 54790
 POSITION(CM)= 1.8216 COUNTS= 54682

POSITION(KCH)= 2.2264 COUNTS= 56599
 POSITION(KCH)= 2.6312 COUNTS= 56906
 POSITION(KCH)= 3.036 COUNTS= 56333
 POSITION(KCH)= 3.4408 COUNTS= 54923
 POSITION(KCH)= 3.8456 COUNTS= 54706
 POSITION(KCH)= 4.2504 COUNTS= 54466
 POSITION(KCH)= 4.6552 COUNTS= 54100
 POSITION(KCH)= 5.06 COUNTS= 55233
 POSITION(KCH)= 5.4648 COUNTS= 54598
 POSITION(KCH)= 5.8696 COUNTS= 53371
 POSITION(KCH)= 6.2744 COUNTS= 53079
 POSITION(KCH)= 6.6792 COUNTS= 54450
 POSITION(KCH)= 7.084 COUNTS= 54253
 POSITION(KCH)= 7.4888 COUNTS= 58326
 POSITION(KCH)= 7.8936 COUNTS= 56801

SAMPLE # 3 RAW DATA GAMMA COUNTS

TIME IS : 18.75 DAYS

MOOD MASS IS : 444.9 GRAMS

POSITION(KCH)= .2024 COUNTS= 47761
 POSITION(KCH)= .6072 COUNTS= 44969
 POSITION(KCH)= 1.012 COUNTS= 49991
 POSITION(KCH)= 1.4168 COUNTS= 53108
 POSITION(KCH)= 1.8216 COUNTS= 54950
 POSITION(KCH)= 2.2264 COUNTS= 57067
 POSITION(KCH)= 2.6312 COUNTS= 55481
 POSITION(KCH)= 3.036 COUNTS= 57110
 POSITION(KCH)= 3.4408 COUNTS= 55027
 POSITION(KCH)= 3.8456 COUNTS= 56841
 POSITION(KCH)= 4.2504 COUNTS= 56296
 POSITION(KCH)= 4.6552 COUNTS= 55517
 POSITION(KCH)= 5.06 COUNTS= 56772
 POSITION(KCH)= 5.4648 COUNTS= 56324
 POSITION(KCH)= 5.8696 COUNTS= 53429
 POSITION(KCH)= 6.2744 COUNTS= 55492
 POSITION(KCH)= 6.6792 COUNTS= 55672
 POSITION(KCH)= 7.084 COUNTS= 55781
 POSITION(KCH)= 7.4888 COUNTS= 60680
 POSITION(KCH)= 7.8936 COUNTS= 57578

SAMPLE # 3 RAW DATA GAMMA COUNTS

TIME IS : 25.83 DAYS

MOOD MASS IS : 443.7 GRAMS

POSITION(KCH)= .2024 COUNTS= 48191
 POSITION(KCH)= .6072 COUNTS= 48600
 POSITION(KCH)= 1.012 COUNTS= 53135
 POSITION(KCH)= 1.4168 COUNTS= 55210
 POSITION(KCH)= 1.8216 COUNTS= 54969
 POSITION(KCH)= 2.2264 COUNTS= 58100
 POSITION(KCH)= 2.6312 COUNTS= 57128
 POSITION(KCH)= 3.036 COUNTS= 58769
 POSITION(KCH)= 3.4408 COUNTS= 56700
 POSITION(KCH)= 3.8456 COUNTS= 57090
 POSITION(KCH)= 4.2504 COUNTS= 56517
 POSITION(KCH)= 4.6552 COUNTS= 56363
 POSITION(KCH)= 5.06 COUNTS= 58424
 POSITION(KCH)= 5.4648 COUNTS= 56730
 POSITION(KCH)= 5.8696 COUNTS= 57316
 POSITION(KCH)= 6.2744 COUNTS= 55955
 POSITION(KCH)= 6.6792 COUNTS= 57426
 POSITION(KCH)= 7.084 COUNTS= 58899
 POSITION(KCH)= 7.4888 COUNTS= 62525
 POSITION(KCH)= 7.8936 COUNTS= 62071

SAMPLE # 3 RAW DATA GAMMA COUNTS

TIME IS : 45.75 DAYS

MOOD MASS IS : 443.7 GRAMS

NOOD PRESS IS : 437.1 GRAMS
POSITION(CM)= .2024 COUNTS= 48692
POSITION(CM)= .6072 COUNTS= 48293
POSITION(CM)= 1.012 COUNTS= 51075
POSITION(CM)= 1.4168 COUNTS= 54353
POSITION(CM)= 1.8216 COUNTS= 56457
POSITION(CM)= 2.2264 COUNTS= 57743
POSITION(CM)= 2.6312 COUNTS= 57094
POSITION(CM)= 3.036 COUNTS= 59332
POSITION(CM)= 3.4408 COUNTS= 57909
POSITION(CM)= 3.8456 COUNTS= 60365
POSITION(CM)= 4.2504 COUNTS= 59436
POSITION(CM)= 4.6552 COUNTS= 58858
POSITION(CM)= 5.06 COUNTS= 58754
POSITION(CM)= 5.4648 COUNTS= 59797
POSITION(CM)= 5.8696 COUNTS= 56813
POSITION(CM)= 6.2744 COUNTS= 59502
POSITION(CM)= 6.6792 COUNTS= 59754
POSITION(CM)= 7.084 COUNTS= 62863
POSITION(CM)= 7.4888 COUNTS= 64539
POSITION(CM)= 7.8936 COUNTS= 63655

FINALIZE DATA (DRY WOOD DATA) FOR SAMPLE #3

FINALIZE DATA (DRY WOOD DATA) FOR SAMPLE # 3

DRY DIMENSIONS ARE 8.573 X 5.047 X 4.341 CM

OVEN EQUIVALENT MOISTURE CONTENT IS 5E-03

NEMO (DRY MASS) IS 318.1 GRAMS

POSITION (CM)=	.123725	COUNTS=	94586
POSITION (CM)=	.581175	COUNTS=	90953
POSITION (CM)=	.968625	COUNTS=	91910
POSITION (CM)=	1.356075	COUNTS=	91957
POSITION (CM)=	1.743525	COUNTS=	89228
POSITION (CM)=	2.130975	COUNTS=	92265
POSITION (CM)=	2.518425	COUNTS=	91708
POSITION (CM)=	2.905875	COUNTS=	91426
POSITION (CM)=	3.293325	COUNTS=	91413
POSITION (CM)=	3.680775	COUNTS=	134420
POSITION (CM)=	4.068225	COUNTS=	94221
POSITION (CM)=	4.455675	COUNTS=	90912
POSITION (CM)=	4.843125	COUNTS=	90694
POSITION (CM)=	5.23057501	COUNTS=	89162
POSITION (CM)=	5.618025	COUNTS=	87708
POSITION (CM)=	6.00547501	COUNTS=	89413
POSITION (CM)=	6.392925	COUNTS=	88503
POSITION (CM)=	6.780375	COUNTS=	89664
POSITION (CM)=	7.16782501	COUNTS=	88654
POSITION (CM)=	7.55527501	COUNTS=	87973

APPENDIX C

SATURATION LEVELS $S(Z,T)$ FOR SAMPLE #3

TABLE VIII

SPECIMEN #3, SATURATION (Z,t)

SPECIMEN NUMBER 3 , SATURATION(Z,T)

	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Z10	Z11	Z12
Z13	Z14	Z15	Z16	Z17	Z18	Z19	Z20					
MASS (GM)												
TIME00	1.015	.893	.909	.902	.863	.897	.876	.963	.974	1.007 ^{.911}	.948	.834
	.88	.817	.838	.826	.823	.832	.796	.766				
	230.4									.795 ^{.795}		
TIME01	.981	.899	.8	.776	.738	.8	.771	.766	.751	1.047 ^{.795}	.846	.788
	.766	.782	.809	.752	.813	.743	.747					
	216.1									.782 ^{.782}		
TIME02	.961	.887	.788	.779	.745	.737	.745	.688	.704	1.04 ^{.782}	.812	.780
	.757	.763	.769	.747	.756	.803	.736	.704				
	213.7									.788 ^{.788}		
TIME03	.962	.894	.782	.738	.713	.713	.705	.668	.728	1.025 ^{.788}	.814	.707
	.731	.754	.74	.737	.753	.776	.694	.663				
	209.4									.755 ^{.755}		
TIME04	.979	.879	.762	.724	.69	.717	.707	.677	.73	1.020 ^{.755}	.891	.763
	.06	.724	.716	.693	.743	.726	.633	.645				
	207.2									.734 ^{.734}		
TIME05	.98	.899	.779	.716	.666	.666	.646	.658	.701	1.095 ^{.734}	.768	.717
	.678	.666	.677	.72	.661	.688	.545	.577				
	206.7									.705 ^{.705}		
TIME06	.997	1.028	.87	.768	.658	.652	.689	.635	.708	1.033 ^{.705}	.712	.673
	.631	.613	.675	.645	.623	.641	.478	.554				
	201.8									.676 ^{.676}		
TIME07	.982	.897	.767	.703	.657	.622	.64	.586	.647	1.020 ^{.676}	.705	.647
	.582	.601	.556	.631	.57	.548	.427	.426				
	200.6									.615 ^{.615}		
TIME08	.905	.908	.834	.729	.612	.632	.641	.57	.631	1.027 ^{.615}	.63	.574
	.73	.512	.571	.526	.503	.437	.372	.383				
	194											

WHERE TIMES TIME00, TIME01, ... ARE (DAYS):

0 .75 1.75 3.9 6.75 10.75 18.75 25.83 45.75

AND LOCATIONS Z1 TO Z20 ARE (CM):

.2024 .6072 1.012 1.4168 1.8216 2.2264 2.6312 3.036 3.4408 3.8456 4.2504 4.6552 5.06 5.4648 5.8696 6.2744 6.6792 7.084 7.4888 7.8936

APPENDIX D

CURVE FIT RESULTS FOR SAMPLE #3

SAMPLE #3, SATURATION AS A FUNCTION OF LOCATION

SPECIMEN # 3

DATA FILE IS '0 3 S0FLOC'

SATURATION AS A FUNCTION OF LOCATION. RANGE OF LOCATION IS $0 \leq Z \leq 8$ CENTIMETER. RANGE OF SATURATION IS $0 \leq S \leq 1$. THE EQUATION OF $S=F(Z)$ IS DIVIDED BETWEEN TWO REGIONS. THE FIRST PART ($Z=0$ & UP) IS A LINEAR EQUATION $S=G+H*Z$. THE SECOND PART IS A POWER EQUATION $S=E*(Z+F)$, OR A QUADRATIC EQUATION $S=K0+K1*Z+K2*Z^2$. THE CORRELATION COEFFICIENT $-1 \leq R \leq 1$ IS A MEASURE OF GOODNESS OF FIT. THE CLOSER ABS(R) IS TO 1 THE BETTER FIT WE HAVE.

LINEAR EQ.

POWER EQ.

QUADRATIC EQ.

 $S=G+H*Z$ $S=E*(Z+F)$ $S=K0+K1*Z+K2*Z^2$

SPECIMEN # 3

RUN # 0

LINEAR G= 1.07701351 H=-.301944715 R=-1.00000000

POWER E= .918396433 F=-.0519087834 R=-.790546005

QUADRATIC K0= .935319138 K1=-.0123864737 K2=-7.09332583E-04 R= .95296594

RUN # 1

LINEAR G= 1.02187373 H=-.201871597 R=-1.00000012

POWER E= .840538779 F=-.0501977748 R=-.691109339

QUADRATIC K0= .88829508 K1=-.0450699925 K2= 4.14871248E-03 R= .960353559

RUN # 2

LINEAR G= .998306592 H=-.182579835 R=-1.00000005

POWER E= .821359351 F=-.055223664 R=-.709129071

QUADRATIC K0= .878382887 K1=-.052910263 K2= 5.82041033E-03 R= .956064431

RUN # 3

LINEAR G= .996126263 H=-.167360739 R=-1.00000018

POWER E= .806013237 F=-.0644958118 R=-.691280364

QUADRATIC K0= .868563625 K1=-.0575368522 K2= 5.35948327E-03 R= .956248144

RUN # 4

LINEAR G= 1.02877495 H=-.245473132 R=-.999969976

POWER E= .800117891 F=-.0795127506 R=-.766210874

QUADRATIC K0= .86292978 K1=-.0559507808 K2= 4.5578214E-03 R= .957054771

RUN # 5

LINEAR G= 1.0213659 H=-.201264339 R=-1.00000004

POWER E= .789641117 F=-.109794173 R=-.800570798

QUADRATIC K0= .868982984 K1=-.0668270039 K2= 4.88572398E-03 R= .951638053

RUN # 6

LINEAR G= .932334229 H= .0765260713 R= 1.00000007

POWER E= .821302384 F=-.164137829 R=-.875405097

QUADRATIC K0= .964245784 K1=-.111327541 K2= 8.33264414E-03 R= .954055029

RUN # 7

LINEAR G= 1.02512462 H=-.209629926 R=-.999999339

POWER E= .768974283 F=-.182404835 R=-.86819168

QUADRATIC K0= .875355539 K1=-.0816149088 K2= 4.42370653E-03 R= .961211286

RUN # 8

LINEAR G= .993580573 H=-.140058611 R=-.999999915

POWER E= .765511767 F=-.235951804 R=-.904704743

QUADRATIC K0= .907579406 K1=-.104483868 K2= 5.67455699E-03 R= .975400087

TABLE X

SAMPLE #3 AND #4, CAPILLARY PRESSURE
AS A FUNCTION OF SATURATION

SPECIMEN # 3

DATA FILE IS '0 3 PCOFSAT QUAD'

CAPILLARY PRESSURE AS A FUNCTION OF SATURATION.

RANGE OF SATURATION IS 0.0<S<1.0

UNITS OF CAPILLARY PRESSURE IS IN DYNE/CM² $(CAP. PRESS.) = C * (SAT.) + D$

WHERE C= 32344.1866 & D=-3.26412881

 $PC = 32344.1866 * S + -3.26412881$ QUADRATIC EQUATION FORM IS $PC = K0 + K1 * S + K2 * (S^2)$ WHERE:

K0= 1011034.37 K1=-1735089.91 K2= 716244.145

THE RANGE OF POSITIONS USED IS [1 , 20]

CORRELATION COEFFICIENT OF THE CURVE FIT FOR POWER EQ. IS .997471943

CORRELATION COEFFICIENT FOR THE QUADRATIC EQ. IS 1

FOR POSITION RANGE OF [1, 2]

NOTE: AT POSITION 1 WE HAVE FULL SATURATION.

LINEAR EQ. OF FORM $PC = A + B * S$

WHERE A= 459064.295 & B=-461860.707

 $PC = 459064.295 + -461860.707 * S$

CORRELATION COEFFICIENT FOR THE LINEAR EQUATION PART IS .999999906

THE CLOSER ABS. VALUE OF R IS TO 1 THE BETTER CURVE FIT WE HAVE.

SPECIMEN # 4

DATA FILE IS '0 4 PCOFSAT QUAD'

CAPILLARY PRESSURE AS A FUNCTION OF SATURATION.

RANGE OF SATURATION IS 0.0<S<1.0

UNITS OF CAPILLARY PRESSURE IS IN DYNE/CM² $(CAP. PRESS.) = C * (SAT.) + D$

WHERE C= 216718.95 & D=-.87365166

 $PC = 216718.95 * S + -.87365166$ QUADRATIC EQUATION FORM IS $PC = K0 + K1 * S + K2 * (S^2)$ WHERE:

K0= 534691.803 K1=-55736.5484 K2=-412110.833

THE RANGE OF POSITIONS USED IS [1 , 20]

CORRELATION COEFFICIENT OF THE CURVE FIT FOR POWER EQ. IS .992945303

CORRELATION COEFFICIENT FOR THE QUADRATIC EQ. IS 1

FOR POSITION RANGE OF [1, 11]

NOTE: AT POSITION 1 WE HAVE FULL SATURATION.

LINEAR EQ. OF FORM $PC = A + B * S$

WHERE A=-444171.845 & B= 823056.307

 $PC = -444171.845 + 823056.307 * S$

CORRELATION COEFFICIENT FOR THE LINEAR EQUATION PART IS .992917462

THE CLOSER ABS. VALUE OF R IS TO 1 THE BETTER CURVE FIT WE HAVE.

APPENDIX E

UNSATURATED PERMEABILITY VALUES FOR SAMPLE #3

TABLE XI.

Specimen #3, Unsaturated Permeability Values.

SEARCHING FOR #0
 UNSATURATED PERMEABILITY VALUES USING SPECIMEN # 3
 UPPER LOCATION RANGE IS 20
 SATURATED PERMEABILITY VALUE IS 5E-05 DARCY

SATURATION	PERMEABILITY (DARCY)	K(S)/K(S<0>)
.791366587	-9.17731767E-05	-1.83546353
.745265184	1.28946196E-05	.257892391
.719127815	2.46141011E-05	.492282023
.692182052	2.40695882E-05	.481391763
.654143523	7.95396461E-06	.159079292
.607238334	-1.76464838E-05	-.352929675
.556310819	-7.46989014E-05	-1.49397803
.498839327	-1.98158682E-04	-3.96317365

UNSATURATED PERMEABILITY VALUES USING SPECIMEN # 3
 UPPER LOCATION RANGE IS 20
 SATURATED PERMEABILITY VALUE IS 1E-04 DARCY

SATURATION	PERMEABILITY (DARCY)	K(S)/K(S<0>)
.791366587	-4.53420984E-05	-.453420984
.745265184	5.67296562E-05	.567296562
.719127815	6.31717445E-05	.631717445
.692182052	5.67692141E-05	.567692141
.654143523	2.75132414E-05	.275132414
.607238334	-3.3177785E-05	-.33177785
.556310819	-1.33415308E-04	-1.33415308
.498839327	-3.90357549E-04	-3.90357549

UNSATURATED PERMEABILITY VALUES USING SPECIMEN # 3
 UPPER LOCATION RANGE IS 20
 SATURATED PERMEABILITY VALUE IS 2E-04 DARCY

SATURATION	PERMEABILITY (DARCY)	K(S)/K(S<0>)
.791366587	4.75200581E-05	.237600291
.745265184	1.44399729E-04	.721998647
.719127815	1.40287031E-04	.701435156
.692182052	1.22168466E-04	.61084233
.654143523	6.6631795E-05	.333158975
.607238334	-6.42403875E-05	-.321201938
.556310819	-2.5084812E-04	-1.2542405
.498839327	-7.74755282E-04	-3.87377641

UNSATURATED PERMEABILITY VALUES USING SPECIMEN # 3
 UPPER LOCATION RANGE IS 20
 SATURATED PERMEABILITY VALUE IS 3E-04 DARCY

SATURATION	PERMEABILITY (DARCY)	K(S)/K(S<0>)
.791366587	1.40382215E-04	.467940715
.745265184	2.32069803E-04	.773566009
.719127815	2.17402318E-04	.724674393
.692182052	1.87567718E-04	.625225726
.654143523	1.05750349E-04	.352501162
.607238334	-9.53029901E-05	-.317676633
.556310819	-3.68280933E-04	-1.22760311
.498839327	-1.15915302E-03	-3.86384338

Specimen #3, Unsaturated Permeability Values Calculated
at Varying Upper Range Locations.

UNSATURATED PERMEABILITY VALUES USING SPECIMEN # 3

UPPER LOCATION RANGE IS 20

SATURATED PERMEABILITY VALUE IS 2E-04 DARCY

```

*****
SATURATION      PERMEABILITY (DARCY)      K(S)/K(S<0>)
.791366587      4.75200581E-05      .237600291
.745265184      1.44399729E-04      .721998647
.719127815      1.40287031E-04      .701435156
.692182052      1.22168466E-04      .61084233
.654143523      6.6631795E-05      .333158975
.607238334      -6.42403875E-05      -.321201938
.556310319      -2.5084812E-04      -1.2542406
.498839327      -7.74755282E-04      -3.87377641
*****

```

UNSATURATED PERMEABILITY VALUES USING SPECIMEN # 3

UPPER LOCATION RANGE IS 19

SATURATED PERMEABILITY VALUE IS 2E-04 DARCY

```

*****
SATURATION      PERMEABILITY (DARCY)      K(S)/K(S<0>)
.793497872      4.81438937E-05      .240719469
.747334412      1.43941301E-04      .719706504
.721394183      1.38329764E-04      .691648818
.694805385      1.1976231E-04      .598811551
.65739157       6.63763357E-05      .331881679
.611601311      -6.25022616E-05      -.312511308
.561394603      -2.42595451E-04      -1.21297725
.504322486      -7.46505466E-04      -3.73252733
*****

```

UNSATURATED PERMEABILITY VALUES USING SPECIMEN # 3

UPPER LOCATION RANGE IS 18

SATURATED PERMEABILITY VALUE IS 2E-04 DARCY

```

*****
SATURATION      PERMEABILITY (DARCY)      K(S)/K(S<0>)
.795753851      5.18090138E-05      .259045069
.749524902      1.41106813E-04      .705534065
.72379432       1.3648896E-04      .6824448
.69758585       1.18565098E-04      .592825492
.660838109      6.65221588E-05      .332610794
.616242178      -6.04295148E-05      -.302147574
.566811515      -2.36071463E-04      -1.18035731
.510176915      -7.21463964E-04      -3.60731982
*****

```

UNSATURATED PERMEABILITY VALUES USING SPECIMEN # 3

UPPER LOCATION RANGE IS 17

SATURATED PERMEABILITY VALUE IS 2E-04 DARCY

```

*****
SATURATION      PERMEABILITY (DARCY)      K(S)/K(S<0>)
.798149602      5.23136863E-05      .261568432
.751851331      1.38646327E-04      .693231633
.726344479      1.34318567E-04      .671592833
.700542012      1.17200529E-04      .586002642
.664507709      6.5791576E-05      .32895788
.621196123      -5.86940509E-05      -.293470254
.572604392      -2.29533153E-04      -1.14766577
.516451253      -6.99000689E-04      -3.49500344
*****

```

UNSATURATED PERMEABILITY VALUES USING SPECIMEN # 3

UPPER LOCATION RANGE IS 16

SATURATED PERMEABILITY VALUE IS 2E-04 DARCY

SATURATION	PERMEABILITY (DARCY)	K(S)/K(S(0))
.800703089	5.71730462E-05	.285865231
.754331185	1.35404768E-04	.67702384
.729064029	1.31589588E-04	.657947241
.703696931	1.14973464E-04	.574892322
.668429716	6.59141149E-05	.329570574
.626505285	-5.71719102E-05	-.285859551
.578824623	-2.24096105E-04	-1.12048053
.523203979	-6.79723383E-04	-3.39861692

UNSATURATED PERMEABILITY VALUES USING SPECIMEN # 3

UPPER LOCATION RANGE IS 15

SATURATED PERMEABILITY VALUE IS 3E-04 DARCY

SATURATION	PERMEABILITY (DARCY)	K(S)/K(S(0))
.803435938	5.74106525E-05	.287053263
.756985519	1.36520915E-04	.682604576
.731976305	1.29185242E-04	.645926208
.707078162	1.13698092E-04	.568490457
.67263956	6.41943287E-05	.320971643
.632220681	-5.53988002E-05	-.276994041
.585534544	-2.19702347E-04	-1.09851173
.530506199	-6.62882304E-04	-3.31441152

UNSATURATED PERMEABILITY VALUES USING SPECIMEN # 3

UPPER LOCATION RANGE IS 14

SATURATED PERMEABILITY VALUE IS 2E-04 DARCY

SATURATION	PERMEABILITY (DARCY)	K(S)/K(S(0))
.806374507	6.08924531E-05	.304462265
.759839994	1.34542095E-04	.672710475
.735109762	1.27507262E-04	.637536309
.71071934	1.12039524E-04	.560447619
.67718055	6.36956727E-05	.318478363
.638404856	-5.44505477E-05	-.272252739
.59281073	-2.14452075E-04	-1.07226038
.538445477	-6.49602353E-04	-3.24801176

UNSATURATED PERMEABILITY VALUES USING SPECIMEN # 3

UPPER LOCATION RANGE IS 13

SATURATED PERMEABILITY VALUE IS 2E-04 DARCY

SATURATION	PERMEABILITY (DARCY)	K(S)/K(S(0))
.80955136	6.37248151E-05	.318624075
.762926321	1.32169505E-04	.660847523
.738499578	1.25390844E-04	.626954222
.714662079	1.1072641E-04	.553632048
.682106366	6.3595172E-05	.31797586
.645135593	-5.31295139E-05	-.265647569
.600748602	-2.11156835E-04	-1.05578417
.547131226	-6.38273877E-04	-3.19136938

APPENDIX F

SAMPLE DATA REDUCTION

Step by step calculation for sample #3.

Raw data in form of gamma counts is taken from computer floppy disk.

The following constants are used in calculation (Spolek 1981a).

Cup weight = 243.1 grams

$\mu_{wd} = .189 \text{ cm}^2/\text{gm}$

$\mu_w = .201 \text{ cm}^2/\text{gm}$

G_{wd} = specific gravity of wood on a local basis

$$G_{wd} = \bar{\rho}_{wd}$$

FSP = Fiber Saturation Point = 0.3

$\emptyset = 0.63$ porosity = (volume of wood-volume of cell walls)/(volume of wood)

$G_{cw} = 1.53$ = Specific gravity of wood cell wall

Wet dimensions 8.956 x 5.065 x 4.483(absorption length)cm

Initial wet mass (of wood sample itself) = 230.4 gm

Dry dimensions 8.573 x 5.047 x 4.341 cm

EMC = Equilibrium moisture content of oven = 5×10^{-3}

Final dry mass of sample = 75 gm

$V_{wet} = 203.36 \text{ cm}^3$ volume

$V_{dry} = 187.83 \text{ cm}^3$ dry wood + EMC

$$\rho_{measured} = \frac{m_{wd} + EMC}{V_{wd} + EMC} = 0.397 \text{ gm/cm}^3 \quad (\text{dry wood})$$

$$\bar{\rho}_{wd} = \frac{\rho_{measured}}{1 + EMC(V_{wd}/V_{wd} + EMC)} = \frac{0.397}{1 + (.005)(1)} = .395 \text{ gm/cm}^3$$

$$G_{wd} = \bar{\rho}_{wd} = .395$$

$$\Delta m = M_{\max} - FSP = \frac{G_{cw} - G_{wd}}{G_{cw} \times G_{wd}} = \frac{1.53 - .395}{1.53 \times .395} = 1.86$$

Moisture difference (Spolek 1981a)

Gamma Count measurements are reduced as follow:

For dry wood,

$$N_{wd} = N_{wd+EMC} \times \text{Exp}(\mu_{wd} \cdot \rho_{wd} \cdot L_{wd} \cdot EMC)$$

Where

N_{wd} = Corrected gamma count.

$N_{\text{meas.}}$ = Measured gamma count.

$$N_{wd+EMC} = \frac{1}{(1/N_{\text{meas.}} - \tau)} = \frac{N_{\text{meas.}}}{1 - \tau \times N_{\text{meas.}}}$$

$\tau = 8 \times 10^{-6}$ seconds/count, for 10 seconds count (instrument dead time in order to distinguish between two gamma radiation pulses).

$$N_{wd+EMC} = \frac{N_{\text{meas.}}}{1 - \tau \times N_{\text{meas.}}} = \frac{N_{\text{meas.}}}{1 - 8 \times 10^{-7} \times N_{\text{meas.}}}$$

$$N_{wd} = N_{wd+EMC} \times \text{Exp}(0.189 \times 0.395 \times 4.341 \times 0.005)$$

Wet wood gamma count correction is done by:

$$N_{wd+w} = \frac{N_{wd+w(\text{measured})}}{1 - 8 \times 10^{-7} \times N_{wd+w(\text{measured})}}$$

M = Moisture content= (weight of water in wood)/(weight of bone dry wood). Moisture content is calculated using the following equation,

$$M = \frac{-V_{wd+w}}{V_{wd}} \cdot \frac{1}{\mu_w \rho_{wd} L_{wd+w}} \left[\text{Ln} \frac{N_{wd+w}}{N_{wd}} + \rho_{wd} \mu_{wd} (L_{wd+w} - L_{wd}) \right]$$

$$M = - \frac{203.36}{187.83} \cdot \frac{1}{0.201 \times 0.395 \times 4.483} \left[\text{Ln} \frac{N_{wd+w}}{N_{wd}} + 0.395 \times 0.189 (4.483 - 4.341) \right]$$

$$M = -3.042 \left[\ln \frac{N_{wd+w}}{N_{wd}} + 0.0106 \right]$$

Having calculated moisture contents, saturation levels are reduced as follows:

$$S = \frac{M - FSP}{M_{\max} - FSP} = \frac{M - FSP}{\Delta M} = \frac{M - 0.3}{1.86}$$

Sample results for saturation at different time intervals for location intervals of $\Delta Z = 0.4048$ cm ($0 < Z < 8$ cm) are provided in appendix C. At final stage of experiment steady state conditions exist and body force equals P_c , at this stage very little moisture drains out of wood.

At steady state capillary pressure is calculated as follows:

$$P_c = \rho_l w^2 Z \left(R - \frac{Z}{2} \right)$$

where

$$R = 24 \text{ cm}$$

$$0 \leq Z \leq 8 \text{ cm}$$

$$w = 500 \text{ RPM (Rev./min.)} = \frac{500 \times 2\pi}{60} = 52.36 \text{ rad/sec.}$$

$$\rho_l = 1 \text{ gm/cm}^3$$

$$P_c = 2741.57 \times Z(24 - Z/2)$$

$$P_c \Big|_{Z=0} = 0 \quad ; \quad P_c \Big|_{Z=8} = 438651 \text{ gm/cm} \cdot \text{sec}^2 \quad (\text{dyn/cm}^2)$$

The equation used to calculate the unsaturated permeability is:

$$k(S(L)) = [C(S(L)) \cdot S'(L) - B(L)]^{-1} \times \{k(S(0)) [C(S(0)) \cdot S'(0) - B(0)] -$$

$$\mu \int_0^L \left(\frac{\partial S}{\partial t} \right) \partial Z \}$$

where

$$C(S(Z)) = \frac{\partial P_c}{\partial S}, \text{ curve fit values (power equation) are used.}$$

$$B(Z) = \rho_w g = \rho_w w^2 (R-Z) = 2741.57(24-Z) \frac{\text{gm}}{\text{cm}^2 \text{sec}^2} \quad (\text{dyne/cm}^3)$$

$$S' = \frac{dS}{dZ}, \text{ curve fit values (power equation) are used.}$$

$$\mu = \text{viscosity of water} = 1.002 \times 10^{-2} \text{ gm/cm} \cdot \text{sec}$$

Saturated tangential permeability is (Comstock, 1970):

$$4.935 \times 10^{-13} \text{ cm}^2 = 0.5 \times 10^{-4} \text{ darcy} \leq k(S(0)) \leq 3.0 \times 10^{-4} \text{ darcy} = 2.961 \times 10^{-12} \text{ cm}^2$$

$$\int_0^L \frac{\partial S}{\partial t} dz \approx \frac{d}{dt} \int_0^L S \cdot dz$$

in calculation for sample #3 range of integration is from Z_1 to Z_{20}

where Z (total length) is divided into 20 intervals, starting at

$Z_1 = 0.2024 \text{ cm}$ and ending at $Z_{20} = 7.8936 \text{ cm}$ with interval $\Delta Z = 0.4048 \text{ cm}$. Thus

$$\frac{d}{dt} \int_1^L S \cdot dz = \frac{1}{\Delta t} \left[\left(\sum_{i=1}^{20} S(Z_i) \right) \times 0.4048 \text{ cm} \Big|_{t_2} - \left(\sum_{i=1}^{20} S(Z_i) \right) \times 0.4048 \text{ cm} \Big|_{t_1} \right]$$

values of time (for calculating Δt) are provided in appendix D along with curve fit values for $S(Z)$. Curve fit values for $P_c(s)$ are also provided in appendix D.

Curve fit values for sample #3 are done for the location range of $Z_1 = 0.2024 \text{ cm}$ to $Z_{20} = 7.8936 \text{ cm}$ (appendix D). All initial starting points are at $l=Z_1$, and all ending points are at $L=Z_{20}$ throughout the calculations for scan time 03 (saturation profile) sample curve fit result is:

$$S(Z) = .80601 \times Z^{-.06449} \quad \text{therefore,}$$

$$S'(Z) = -.051979 \times Z^{-1.06449} \text{ at } Z_1 \text{ and } Z_{20}$$

$$P_C(s) = 32344 \times S^{-3.264} \quad \text{therefore}$$

$$\frac{\partial P_C}{\partial S} = -105571 \times S^{-4.264} \quad \text{at } S_{Z_1} \text{ and } S_{Z_{20}}$$

for additional values refer to appendix D. To calculate S_{Z_1} and $S_{Z_{20}}$ average values at each location are calculated between the two runs under consideration. Averages are calculated using curve fit values for saturation to both avoid actual data fluctuation and also provide a consistent pattern for saturation levels at end location Z_{20} . Timing of runs are as follows (sample #3).

TABLE XIII
SAMPLE #3 EXPERIMENT TIME PERIODS

Days	Seconds	ΔT (Seconds)
$t_1 = 0$	0	
$t_2 = 0.75$	64800	64800
$t_3 = 1.75$	151200	86400
$t_4 = 3.9$	336960	185760
$t_5 = 6.75$	583200	246240
$t_6 = 10.75$	928800	345600
$t_7 = 18.75$	1620000	691200
$t_8 = 25.83$	2231712	611712
$t_9 = 45.75$	3952800	1721088

Actual unsaturated permeability value $k(S(L))$ will be calculated for run 4 (values for scan time 03 and 04).

For Scan Time 03 we have:

$$S = .80601 \times Z^{-.06449}$$

$$S' = -.051979 \times Z^{-1.06449}$$

$$S(Z_{20}) = .7055 ; S(Z_1) = .962 \text{ (for } S(Z_1) \text{ actual data is used)}$$

$$S'(Z_{20}) = -.00576 ; S'(Z_1) = -0.2847$$

$$\sum_{i=1}^{20} S(Z_i) = 15.0855 \text{ (Note that } S(Z_{10}) \text{ has been modified as an average of } S(Z_9) \text{ and } S(Z_{11}))$$

For Scan Time 04 we have:

$$S = .80012 \times Z^{-.07951}$$

$$S' = -.06362 \times Z^{-1.07951}$$

$$S(Z_{20}) = .6789 ; S(Z_1) = .979 \text{ (for } S(Z_1) \text{ actual data is used)}$$

$$S'(Z_{20}) = -.00684 ; S'(Z_1) = -.3569$$

$$\sum_{i=1}^{20} S(Z_i) = 14.7505 \text{ (Note that } S(Z_{10}) \text{ has been modified as an average of } S(Z_9) \text{ and } S(Z_{11}))$$

Taking averages we have:

$$S(Z_{20}) = .6922 \text{ (Note that this is the average based on curve fits)}$$

$$S(Z_1) = .9705$$

$$S'(Z_{20}) = -.0063$$

$$S'(Z_1) = -.3208$$

$$C(S(Z)) = \frac{dP_c}{dS} = -105571 \times S^{-4.264}$$

Thus

$$C(S(Z_1)) = -119949 \quad ; \quad C(S(Z_{20})) = -506754$$

and

$$B(Z_1) = 65243 \text{ dyne/cm}^3 \quad ; \quad B(Z_{20}) = 44157 \text{ dyne/cm}^3$$

$$\int_{Z_1}^{Z_{20}} \left(\frac{\partial S}{\partial t} \right) dZ = \frac{.4048}{185760} (14.7505 - 15.0855) = -0.73 \times 10^{-6} \text{ cm/sec}$$

Plugging in all the terms in equations used to calculate $k(S(L))$ we will have:

$$\text{for } k(\text{sat.}) = 2 \times 10^{-4} \text{ darcy} = 1.974 \times 10^{-12} \text{ cm}^2$$

$$k(S(L)) = \frac{1.974 \times 10^{-12} \times [-119949 \times (-.3208) - 65243] - 1.002 \times 10^{-2} \times .63 (-.73 \times 10^{-6})}{-506754 (-.0063) - 44157}$$

$$k(S(L)) = \frac{-5.28 \times 10^{-8} + 4.608 \times 10^{-9}}{-40964} = 1.1772 \times 10^{-12} \text{ cm}^2$$

$$\frac{k(S(L))}{k(\text{sat.})} = .596 \approx .6$$

which indicates that at $S(L) = .69$ $k(S(L))/k(\text{sat.}) = 0.6$

for $k(\text{sat.}) = 2 \times 10^{-4}$ darcy

Within the calculated saturation levels for all specimen there were two sets of data points that seemed to be wrong. One set of bad saturation level data points were due to a bad dry wood gamma count. This set was easily detected by using Chauvenet's criterion (Holman, 1978; Schenck, 1979) on dry wood gamma counts for all the samples. Since each sample had 20 dry wood gamma counts, within each sample any data point that was more than $(2.23 \times \text{standard deviation})$ away from the average of data points was considered a bad data point. The resulting saturation levels at those locations for all the runs of each sample were not used for calculations of curve fits, and for calculation of integral part in equation resulting in

$k(S(L))$ their value was changed to the average of their adjacent data points in each gamma scan (experiment run). The other set of bad saturation level data points were caused by a bad wet wood gamma scan. Since the author knew of no statistical procedure to detect these point, visual observation of saturation versus location plots was utilized to detect these points. These data points were corrected to the average value of data points at the same location but at preceeding and following wet wood gamma scans. Total number of second set of bad data points was 12 out of a total 3720 data points. A list of second set of bad data is:

TABLE XIV

BAD DATA POINTS CAUSED BY WET GAMMA COUNTS

Sample #	S(Scan Time, location #i(Z _i)) : Old value to modified value		
1	S(0,1)	:	1.419 to .795
2	S(0,1)	:	1.278 to .740
6	S(4,1)	:	0 to .782
6	S(6,6)	:	1.011 to .829
10	S(8,1)	:	1.3 to .811
10	S(9,1)	:	.463 to .811
12	S(8,1)	:	1.55 to .947
14	S(0,1)	:	1.549 to .961
16	S(0,1)	:	1.76 to .983
17	S(0,1)	:	1.447 to .913
17	S(7,1)	:	1.064 to .913
18	S(3,1)	:	1.029 to .968

A list for the first set of bad data caused by bad dry wood gamma count is:

TABLE XV

BAD DATA POINTS CAUSED BY DRY GAMMA COUNTS

Sample #	Rejected location Z_i ;	Sample #	rejected location Z_i
3	Z_{10}	10	Z_{17}
4	Z_{18}	12	Z_8
5	Z_7	13	Z_1
7	Z_3	16	Z_{13}
8	Z_7	17	Z_{12}
9	Z_9		

Figures 63 to 66 show photocopies of some wood samples after they are oven dried. The cracks that have caused some bad data points are shown in these figures.

Figure 63. Photocopy of wood samples 1 to 6 reduced 65%.

Figure 64. Photocopy of wood samples 1 to 6 reduced 65%.

Figure 65. Photocopy of wood samples 13 to 18 reduced 65%.

Figure 66. Photocopy of wood samples 13 to 18 reduced 65%.

APPENDIX G

COMPUTER SOFTWARES DEVELOPED IN BASIC FOR COMMODORE 64

```
1 REM THIS PROGRAM UNLOADS DATA FROM THE
2 REM TAPE AND LOADS IT INTO THE DISK FOR
3 REM THE INITIALIZATION PART.
4 REM FARID PIROOZMANDI APRIL 23, 1983
10 OPEN 10,1,0,"01WW"
20 INPUT#10,L1
30 INPUT#10,M1
40 INPUT#10,O1
50 INPUT#10,M1
60 INPUT#10,UND
70 INPUT#10,UH20
80 INPUT#10,TAU
90 CLOSE 10
100 PRINTL1
110 PRINTW1
120 PRINTO1
130 PRINTM1
140 PRINTUND
150 PRINTUH20
160 PRINTTAU
170 REM
180 REM
190 REM
200 OPEN3,0,2,"1:01WW.SEO,WRITE"
210 PRINT#3,L1CHR$(13)
220 PRINT#3,W1CHR$(13)
230 PRINT#3,O1CHR$(13)
240 PRINT#3,M1CHR$(13)
250 PRINT#3,UNDCHR$(13)
260 PRINT#3,UH20CHR$(13)
270 PRINT#3,TAUCHR$(13)
280 CLOSE3
READY.
```

READY.

```

1 REM THIS PROGRAM UNLOADS DATA FROM THE
2 REM TAPE AND LOADS IT INTO THE DISK FOR
3 REM THE FINALIZE PART.
4 REM FARID PIROOZMANDI APRIL 25, 1983
5 DIM P(30),NWD(30)
10 OPEN 10,1,0,"0100"
20 INPUT#10,LDRY
30 INPUT#10,WDRY
32 INPUT#10,DDRYP
34 INPUT#10,EMC
36 INPUT#10,MEMC
40 FOR JJ=1 TO 20
50 INPUT#10,P(JJ),NWD(JJ)
60 NEXT JJ
65 CLOSE 10
67 PRINTLDRY;WDRY;DDRYP;EMC;MEMC
70 FOR JJ=1 TO 20
80 PRINT"POSITION(CM)=";P(JJ);"COUNTS=";NWD(JJ)
95 NEXT JJ
100 C$=","
200 OPEN3,8,2,"1:0100,SEQ,WRITE"
210 PRINT#3,LDRYCHR$(13)
220 PRINT#3,WDRYCHR$(13)
222 PRINT#3,DDRYPCHR$(13)
224 PRINT#3,EMCCHR$(13)
226 PRINT#3,MEMCCHR$(13)
230 FOR JJ=1 TO 20
240 PRINT#3,P(JJ),C$,NWD(JJ)CHR$(13)
250 NEXT JJ
260 CLOSE3
READY.

```

READY.

```

1 REM THIS PROGRAM UNLOADS DATA FROM THE
2 REM TAPE AND LOADS IT INTO THE DISK FOR
3 REM THE DATA COLLECT PART.
4 REM FARID PIROOZMANDI APRIL 23, 1983
5 DIM P(30),COUNTS(30)
10 OPEN 10,1,0,"0100"
20 INPUT#10,TM
30 INPUT#10,MI
40 FOR DD=1 TO 20
50 INPUT#10,P(DD),COUNTS(DD)
60 NEXT DD
65 CLOSE 10
70 FOR DD=1 TO 20
80 PRINT"POSITION(CM)=",P(DD),"COUNTS=",COUNTS(DD)
85 NEXT DD
100 C$=","
200 OPEN3,0,2,"1:0100,SEQ,WRITE"
210 PRINT#3,TMCHR$(13)
220 PRINT#3,MICHR$(13)
230 FOR DD=1 TO 20
240 PRINT#3,P(DD),C$,COUNTS(DD)CHR$(13)
250 NEXT DD
260 CLOSE3
READY.

```

READY.

```

1 REM THIS PROGRAM IS USED TO INPUT DATA
2 REM MANUALLY INTO THE DISK FOR THE FINALIZE
3 REM PART.
4 REM FARID PIROOZMANDI JUNE 17TH,1983
5 DIM P(30),NMD(30)
20 INPUT"DRY LENGTH";LDRY
30 INPUT"DRY WIDTH ";WDRY
32 INPUT"DRY DEPTH ";DDRYP
34 INPUT"OVEN EMC";EMC
36 INPUT"DRY MASS PLUS EMC AND CONTAINER";MEMC
40 FOR JJ=1 TO 20:PRINT"DATA SET #";JJ
50 INPUT"POSITION(CM)";P(JJ);INPUT"COUNTS";NMD(JJ)
60 NEXT JJ
67 PRINTLDRY;WDRY;DDRYP;EMC;MEMC
70 FOR JJ=1 TO 20
80 PRINT"POSITION(CM)=";P(JJ);"COUNTS=";NMD(JJ)
85 NEXT JJ
100 C$=","
200 OPEN3,8,2,"1:1300,SEQ,WRITE"
210 PRINT#3,LDRYCHR$(13)
220 PRINT#3,WDRYCHR$(13)
222 PRINT#3,DDRYPCHR$(13)
224 PRINT#3,EMCCHR$(13)
226 PRINT#3,MEMCCHR$(13)
230 FOR JJ=1 TO 20
240 PRINT#3,P(JJ),C$,NMD(JJ)CHR$(13)
250 NEXT JJ
260 CLOSE3
READY.

```

READY.

```
1 REM THIS PROGRAM INPUTS VALUES OF THE
2 REM MASS OF THE CONTAINORS FOR EACH
3 REM SPECIMEN FOR EACH SET OF DATA ON
4 REM THE DATA DISK IN THE DISK DRIVE
5 REM NUMBER 1.
6 REM FARID PIROOZMANDI JUNE 21, 1983
10 REM INPUT DATA.
20 DIM MC(99)
30 FOR I=1 TO 6
40 PRINT "CONTAINOR MASS FOR SPECIMEN #";I;"IN GRAMS"
50 INPUT MC(I)
60 NEXT I
70 FOR I=1 TO 6
80 PRINT"MASS OF CONTAINOR FOR SPECIMEN #";I;"IS      ";MC(I)
90 NEXT I
100 REM CHECK FOR ACCURACY OF INPUT.
110 PRINT"IF VALUES ARE CORRECT HIT RETURN"
120 PRINT"OTHERWISE STOP THE PROGRAM AND RUN IT AGAIN."
130 INPUT#
140 OPEN3,8,2,"1:01MC,SEQ,WRITE"
150 FOR I=1 TO 6
160 PRINT#3,MC(I)CHR$(13)
170 NEXT I
180 CLOSE3
190 END
READY.
```

READY.

```

1 REM THIS PROGRAM READS DATA FROM DISK
2 REM FOR DATA COLLECT PART AND PRINTS IT
3 REM OUT. THEN IT ERASES THE DATA FILE
4 REM IN THE DISK, MODIFIES THE DATA AND
5 REM LOADS THE MODIFIED DATA BACK INTO THE
6 REM DISK.
8 REM FARID PIROOZMANDI APRIL 27, 1983
9 DIM P(90),COUNTS(90)
10 OPEN3,8,9,"1:0604,SEQ,READ"
110 INPUT#3,TM
111 INPUT#3,MI
112 FOR DD= 1 TO 20
113 INPUT#3,P(DD),COUNTS(DD)
114 NEXT DD
120 CLOSE3
121 REM THIS PART ERASES DATA FILE IN DISK
122 OPEN1,8,15
123 PRINT#1,"S1:0604"
124 CLOSE 1
125 REM THIS PART MODIFIES THE DATA.
126 TM=6.75
130 PRINTTM
140 PRINTMI
150 FOR DD=1 TO 20
160 PRINT"POSITION(CM)=";P(DD);"COUNTS=";COUNTS(DD)
170 NEXT DD
198 C#=","
200 OPEN3,8,2,"1:0604,SEQ,WRITE"
210 PRINT#3,TMCHR$(13)
220 PRINT#3,MICHR$(13)
230 FOR DD=1 TO 20
240 PRINT#3,P(DD),C#,COUNTS(DD)CHR$(13)
250 NEXT DD
260 CLOSE 3
270 END
READY.
```


READY.

```

1 REM*****
2 REM*
3 REM* MOISTURE AND SATURATION LEVEL *
4 REM* CALCULATION PROGRAM *
5 REM*
6 REM* FARID PIROOZMANDI *
7 REM* JUNE 22, 1983 *
8 REM* MODIFIED DEC. 11/84 *
9 REM*****
10 REM THIS PROGRAM CALCULATES THE
11 REM MOISTURE CONTENT AND ALSO THE
12 REM SATURATION LEVEL OF WOOD SPECIMEN
13 REM FOR EACH LOCATION IN THE WOOD
14 REM AT EACH TIME INTERVAL.
15 REM INPUT TO THE PROGRAM IS THE DATA
16 REM OBTAINED BY THE EXPERIMENTS
17 REM CONDUCTED AT WASHINGTON STATE
18 REM UNIVERSITY FOR THE UNSATURATED
19 REM WOOD PERMEABILITY PROJECT.
20 REM OUTPUT OF THE PROGRAM IS MOISTURE
21 REM CONTENT AND SATURATION OF WOOD
22 REM SPECIMEN AS A FUNCTION OF LOCATION
23 REM AND TIME (TIME ELAPSED IN THE EXPERIMENT).
24 REM
25 REM
26 REM*****
27 REM*
28 REM*REQUIRED MODIFICATIONS TO THE *
29 REM*PROGRAM PRIOR TO EXECUTION. *
30 REM*
31 REM*
32 REM*****
33 REM
34 REM THE FOLLOWING LINES SHOULD BE
35 REM MODIFIED ACCORDING TO THE
36 REM SPECIMEN UNDER CALCULATION AND
37 REM ALSO SET OF DATA UNDER STUDY.
38 REM THE PART TO BE CHANGED IS MARKED ** AND
39 REM SPECIFIED ON THE SCREEN AND THE
40 REM CHANGES ARE SPECIFIED IN ().
41 REM
42 REM
43 REM
44 REM
45 REM1130OPEN3,8,9,"1:'01'HW,SEQ,READ"
46 REM (SPECIMEN #)
47 REM
48 REM1220OPEN3,8,9,"1:'01'DD,SEQ,READ"
49 REM (SPECIMEN #)
50 REM
51 REM1320OPEN3,8,9,"1:'01'HC,SEQ,READ"
52 REM (DATA SET #, 01,02,03,04,...)
53 REM
54 REM1330FOR I='1'TO'6'
55 REM (ADD (DATA SET #)*6 TO EACH,7 TO 12,13 TO 18....)
56 REM
57 REM1505PRINT#4,"DATA FILE IS '01'ID"
58 REM (SPECIMEN #)
59 REM
60 REM1770OPEN3,8,2,"0:'01'ID,SEQ,WRITE"

```

```

-----
940 REM (SPECIMEN #)
941 REM1960 FOR I=1TO'9'
942 REM (# OF DATA FILES COLLECTED IN THE CORRESPONDING DATA SET)
943 REM19700N I GOSUB10000,10001,10002,..., (ADD THE REQUIRED # OF DATA FILES)
944 REM
945 REM2280PRINT#4,"DATA FILE IS '01'NS";I
946 REM2285PRINT#4,"DATA FILE IS '01'NS";I
947 REM (SPECIMEN #)
948 REM
949 REM AFTER LINE 10000 SIMILAR LINES
950 REM SHOULD BE ADDED WITH INCREASING
951 REM LINE NUMBERS AND WITH CORRESPONDING
952 REM DATA FILE #'S WITH RESPECT TO
953 REM THE FILE #'S OF COLLECTED DATA
954 REM IN EACH DATA SET.
955 REM SAMPLE:
956 REM100'08'OPEN3,8,9,"1:010'08'SEQ,READ":RETURN
957 REM
958 REM NOTE THAT IN THE SAME DATA SET
959 REM THE FOLLOWING CHANGE SHOULD BE
960 REM MADE FOR EACH SPECIMEN #.
961 REM10008OPEN3,8,9,"1:'01'08,SEQ,READ":RETURN
962 REM (SPECIMEN #)
963 REM
964 REM THE SAME MODIFICATION SHOULD BE
965 REM CONSIDERED FOR LINES 20000 AND ON
966 REM SAMPLE:
967 REM200'08'OPEN3,8,2,"0:01MS'08',SEQ,WRITE":RETURN
968 REM20008OPEN3,8,2,"0:'01'NS08,SEQ,WRITE":RETURN
969 REM
970 REM
971 REM
972 REM
973 REM
974 REM
975 REM
976 REM
977 REM
978 REM
979 REM
980 REM
981 REM*****
982 REM*
983 REM* THE PROCEDURE FOR LOADING
984 REM* AND UNLOADING DATA FROM
985 REM* DISK & RUNNING THE PROGRAM.
986 REM*
987 REM*****
988 REM
989 REM 1.INSERT DATA SET DISK IN DRIVE 1.
990 REM 2.INSERT PROG. DISK IN DRIVE 0.
991 REM 3.READ PROG. FROM DRIVE 0.
992 REM 4.REPLACE PROG. DISK WITH RESULT DISK (RESULT OF CALCULATION WILL BE
993 REM SAVED ON THIS DISK.).
994 REM 5.MODIFY PROG. FOR DESIRED SPECIMEN AND DATA SET #'S.
995 REM 6.RUN THE PROGRAM.
996 REM
997 REM
998 REM
999 REM
1000 REM START THE CALCULATION.
1010 DIMP(20),HND(20),HC(99),HC(20),HDC(20),COUNTS(20),NP,NO,NS(20)
1100 REM INPUT THE NUMBER OF THE SPECIMEN
1101 REM UNDER STUDY.
1102 INPUT"SPECIMEN NUMBER";SP
1103 REM*****
1104 REM*

```

```

1105 REM* INPUT DATA FOR INITIAL *
1106 REM* CALCULATION *
1107 REM* *
1108 REM*****
1109 REM
1110 REM FIRST READ IN DATA FROM DISK FOR
1120 REM INITIALIZE AND FINALIZE PART.
1130 OPEN3,8,9,"1:01NN,SEQ,READ"
1140 INPUT#3,L1
1150 INPUT#3,N1
1160 INPUT#3,D1
1170 INPUT#3,N1
1180 INPUT#3,UND
1190 INPUT#3,UM20
1200 INPUT#3,TAU
1210 CLOSE3
1220 OPEN3,8,9,"1:01DD,SEQ,READ"
1230 INPUT#3,LDRY
1240 INPUT#3,WDRY
1250 INPUT#3,DDRY:DRY=DDRY
1260 INPUT#3,EMC
1270 INPUT#3,MEMC
1280 FOR JJ=1 TO 20
1290 INPUT#3,P(JJ),HMD(JJ)
1300 NEXT JJ
1310 CLOSE3
1320 OPEN3,8,9,"1:01MC,SEQ,READ"
1330 FOR I=1 TO 6
1340 INPUT#3,MC(I)
1350 NEXT I
1360 CLOSE3
1361 REM*****
1362 REM* CALCULATION OF INITIAL *
1363 REM* PARAMETERS *
1364 REM* *
1365 REM*****
1366 REM
1367 REM
1368 REM
1369 REM
1370 REM START CALCULATION OF ONE TIME
1380 REM CALCULATED PARAMETERS.
1390 VN=D1*L1*N1
1400 VD=DRY*LDRY*WDRY
1410 RM=(MEMC-MC(SP))/VD
1420 RD=RM/(1+EMC)
1430 DM=(1.53-RD)/(1.53*RD)
1440 FOR I=1 TO 20
1450 N(I)=HMD(I)/(1-TAU*HMD(I)*.1)
1460 MD(I)=N(I)*EXP(UND*EMC*RD*DRY)
1470 NEXT I
1471 REM
1472 REM*****
1473 REM* PRINT OUT INITIAL *
1474 REM* PARAMETERS. *
1475 REM* *
1476 REM*****
1477 REM
1480 REM PRINT OUT THE DATA SO FAR CALCULATED
1490 REM FOR THIS SPECIMEN.
1500 OPEN4,4:CMD4
1505 PRINT#4,"DATA FILE IS 01ID"
1510 PRINT#4,"THE FOLLOWING DATA IS FOR SPECIMEN NUMBER"
1520 PRINT#4,
1530 PRINT#4,
1540 PRINT#4,"THE NET DIMENSIONS ARE"

```

```

1550 PRINT#4,"LENGTH X WIDTH X DEPTH<ABSORBING LENGTH> (CM)"
1560 PRINT#4,L1;"X";M1;"X";D1
1570 PRINT#4,"INITIAL NET MASS<GRAMS>";M1-MC<SP>
1580 PRINT#4,"WOOD ATTENUATION COEFFICIENT";
1590 PRINT#4,UWD
1600 PRINT#4,"WATER ATTENUATION COEFF.";
1610 PRINT#4,UH2O
1620 PRINT#4,"DEAD TIME<SECONDS>";TAU
1630 PRINT#4,"THE DRY DIMENSIONS ARE"
1640 PRINT#4,"LENGTH X WIDTH X DEPTH<ABSORBING LENGTH> (CM)"
1650 PRINT#4,LDRY;"X";NDRY;"X";DRY
1660 PRINT#4,"EQUILIBRIUM MOISTURE CONTENT, EMC";EMC
1670 PRINT#4,"FINAL DRY MASS<GRAMS>";MEMC-MC<SP>
1680 PRINT#4,"DENSITY OF DRY WOOD IS (GM/CC)";RD
1690 PRINT#4,"NET VOLUME (CC)";VN
1700 PRINT#4,"DRY VOLUME (WOOD PLUS EMC) (CC)";VD
1710 PRINT#4,"DELTA M IS ";DM
1720 PRINT#4,"DRY WOOD GAMMA COUNTS ARE:"
1730 FOR I=1 TO 20
1740 PRINT#4,"DRY POSITION(CM)";P(I);"COUNTS=";ND(I)
1750 NEXT I
1760 PRINT#4:CLOSE4
1761 REM
1762 REM*****
1763 REM*   SAVE THE INITIAL PARAMETERS *
1764 REM*   IN DISK.                  *
1765 REM*                               *
1766 REM*****
1767 REM
1768 REM
1769 REM
1770 OPEN3,8,2,"0:0110,SEQ,WRITE"
1780 PRINT#3,SPCHR$(13)
1790 PRINT#3,PDCHR$(13)
1800 PRINT#3,VDCHR$(13)
1810 PRINT#3,VNCHR$(13)
1820 PRINT#3,UNCHR$(13)
1825 C$=","
1830 FOR I=1 TO 20
1840 PRINT#3,P(I),C$,ND(I)CHR$(13)
1850 NEXT I
1860 CLOSE3
1870 REM
1871 REM*****
1872 REM*                               *
1873 REM*   CALCULATION OF MOISTURE   *
1874 REM*   CONTENT AND SATURATION LEVEL *
1875 REM*   STARTS HERE.              *
1876 REM*                               *
1877 REM*****
1880 REM
1890 REM
1900 REM
1910 REM
1911 REM*****
1941 REM*                               *
1942 REM*   READ IN DATA FOR THE GAMMA *
1943 REM*   COUNTS.                      *
1944 REM*                               *
1945 REM*****
1946 REM
1947 REM
1948 REM
1949 REM
1950 REM
1955 TI=-1.0

```

```

-----
1960 FOR I=1 TO 9
1965 II=II+1
1970 ON I GOSUB 10000,10001,10002,10003,10004,10005,10006,10007,10008
1980 INPUT#3,TH
1990 INPUT#3,MI
2000 FOR DD=1 TO 20
2010 INPUT#3,P<DD>,COUNTS<DD>
2020 NEXT DD
2030 CLOSE3
2031 REM*****
2032 REM* INITIALIZE CORRECTED GAMMA *
2033 REM* COUNTS TO ZERO, AND THEN *
2034 REM* CALCULATE THEM. *
2035 REM*****
2036 REM
2037 REM
2040 FOR DD=1 TO 20
2045 N<DD>=0.0
2050 REM CHECK FOR BAD DATA. IF FOUND ONE SKIP THAT DATA.
2060 IF COUNTS<DD><1000 THEN 2080
2070 N<DD>=COUNTS<DD>/(1-TAU*COUNTS<DD>*.1)
2080 NEXT DD
2081 REM*****
2082 REM* *
2083 REM* INITIALIZE MOISTURE CONTENT *
2084 REM* AND SATURATION LEVEL TO ZERO *
2085 REM* *
2086 REM*****
2087 REM
2088 REM
2089 REM
2090 FOR DD=1 TO 20
2100 M<DD>=0.0:S<DD>=0.0
2110 NEXT DD
2120 REM
2130 REM
2131 REM*****
2132 REM* *
2133 REM* CALCULATE THE MOISTURE *
2134 REM* CONTENT AND SATURATION LEVEL *
2135 REM* *
2136 REM*****
2137 REM
2138 REM
2139 REM
2140 A1=0.0:A2=0.0
2150 REM
2160 FOR DD=1 TO 20
2162 A1=0.0:A2=0.0
2165 IF ND<DD><=0.00RN<DD><=0.00RVD=0.00RUH2O=0.00RFD=0.00RD1=0.0 THEN 2210
2170 A1=LOG<N<DD>/ND<DD>>+RD*UND*(D1-DRY)
2180 A2=-((VN/VD)*(1/(UH2O*RD*D1)))
2190 M<DD>=A1*A2
2200 S<DD>=(M<DD>-.3)/DM
2210 NEXT DD
2220 REM
2230 REM
2240 REM*****
2241 REM* *
2242 REM* PRINT OUT RESULTS, MOISTURE *
2243 REM* CONTENT, AND SATURATION LEVEL*
2244 REM* *
2245 REM*****
2246 REM
2247 REM
2248 REM

```

```

2250 REM
2260 REM
2270 OPEN#4,CMD4
2275 IF II>9 THEN 2285
2280 PRINT#4,"DATA FILE IS 01MS0";II;GO TO 2290
2285 PRINT#4,"DATA FILE IS 01MS";II
2290 PRINT#4,"SPECIMEN NUMBER";SP
2300 PRINT#4,"TIME IS";TM
2310 PRINT#4,"MASS OF SPECIMEN ALONE IS(GRAMS)";MI-MC(CP)
2320 FOR DD=1 TO 20
2330 PRINT#4,"POSITION(CM)";P(DD);"MOISTURE CONTENT";M(DD);"SATURATION";S(DD)
2340 NEXT DD
2350 PRINT#4;CLOSE4
2360 REM
2361 REM*****
2362 REM*
2363 REM* SAVE RESULTS OF MOISTURE
2364 REM* CONTENT AND SATURATION LEVEL
2365 REM* IN DISK.
2366 REM*
2367 REM*****
2368 REM
2369 REM
2370 REM
2380 ON I GOSUB 20000,20001,20002,20003,20004,20005,20006,20007,20008
2390 PRINT#3,SPCHR$(13)
2400 PRINT#3,THCHR$(13)
2410 DU=MI-MC(SP)
2420 PRINT#3,DUCHR$(13)
2430 C$=","
2440 FORDD=1 TO 20
2450 PRINT#3,P(DD),C$,M(DD),C$,S(DD)CHR$(13)
2460 NEXT DD
2470 CLOSE3
2480 REM
2490 REM
2500 NEXT I
2510 REM
2520 REM
2530 REM
2540 REM
2550 REM
2560 REM*****
2561 REM*
2562 REM* SUBROUTINES FOR READING DATA
2563 REM* FOR THE GAMMA COUNTS (LINES
2564 REM* #10000 AND ON).
2565 REM*
2566 REM* SUBROUTINES FOR SAVING DATA
2567 REM* OF MOISTURE CONTENT AND
2568 REM* SATURATION LEVEL IN DISK
2569 REM* (LINES #20000 AND ON).
2570 REM*
2571 REM*****
2580 REM
2590 REM
2600 REM
2610 REM
2620 REM
2630 REM
2640 REM
2650 END
10000 OPEN#3,8,9,"1:0100,SEQ,READ":RETURN
10001 OPEN#3,8,9,"1:0101,SEQ,READ":RETURN
10002 OPEN#3,8,9,"1:0102,SEQ,READ":RETURN
10003 OPEN#3,8,9,"1:0103,SEQ,READ":RETURN

```

```
10004 OPEN3,8,9,"1:0104,SEQ,READ":RETURN
10005 OPEN3,8,9,"1:0105,SEQ,READ":RETURN
10006 OPEN3,8,9,"1:0106,SEQ,READ":RETURN
10007 OPEN3,8,9,"1:0107,SEQ,READ":RETURN
10008 OPEN3,8,9,"1:0108,SEQ,READ":RETURN
20000 OPEN3,8,2,"0:01MS00,SEQ,WRITE":RETURN
20001 OPEN3,8,2,"0:01MS01,SEQ,WRITE":RETURN
20002 OPEN3,8,2,"0:01MS02,SEQ,WRITE":RETURN
20003 OPEN3,8,2,"0:01MS03,SEQ,WRITE":RETURN
20004 OPEN3,8,2,"0:01MS04,SEQ,WRITE":RETURN
20005 OPEN3,8,2,"0:01MS05,SEQ,WRITE":RETURN
20006 OPEN3,8,2,"0:01MS06,SEQ,WRITE":RETURN
20007 OPEN3,8,2,"0:01MS07,SEQ,WRITE":RETURN
20008 OPEN3,8,2,"0:01MS08,SEQ,WRITE":RETURN
30000 END
READY.

READY.

READY.
```

```

10 REM*****
20 REM*
30 REM*  CAPILLARY PRESSURE AS
40 REM*  A FUNCTION OF SATURATION.
42 REM*  MODIFIED VERSION
45 REM*
50 REM*      D      2
60 REM*  PC=C*S , PC=K0+K1*S+K2*S
70 REM*  PC=A+B*S
75 REM*
80 REM*  FARID PIROOZMANDI
90 REM*  DECEMBER 20TH, 1984
95 REM*
97 REM*****
100 REM
110 REM
120 REM
130 REM THIS PROGRAM READS IN DATA FROM
140 REM DISK FOR THE SATURATION LEVEL
150 REM OF EACH SPECIMEN AND THEN CALCULATES
160 REM THE CORRESPONDING CAPILLARY PRESSURE.
170 REM USING THESE DATA THE PROGRAM WILL
180 REM CALCULATE THREE EQUATIONS DESCRIBING
190 REM PC AS A FUNCTION OF SATURATION.
200 REM
210 REM THE DATA DISK SHOULD BE IN DRIVE 1
220 REM
230 REM THE DISK ON WHICH EQUATION IS
240 REM SAVED SHOULD BE IN DRIVE 0.
250 REM
255 DIMP(20),M(20),S(20),PC(20),NS(18),NE(18),Z(20),T(20)
260 REM ENTER STARTING & ENDING POINTS.
262 NS(1)=4:NE(1)=20:NS(2)=4:NE(2)=18
264 NS(2)=4:NE(2)=18:NS(3)=1:NE(3)=20
266 NS(4)=11:NE(4)=20:NS(5)=7:NE(5)=19
268 NS(6)=7:NE(6)=20:NS(7)=4:NE(7)=15
270 NS(8)=6:NE(8)=15:NS(9)=1:NE(9)=20
272 NS(10)=4:NE(10)=20:NS(11)=2:NE(11)=18
274 NS(12)=3:NE(12)=18:NS(13)=7:NE(13)=20
276 NS(14)=7:NE(14)=13:NS(15)=5:NE(15)=14
278 NS(16)=5:NE(16)=13:NS(17)=4:NE(17)=16
280 NS(18)=7:NE(18)=20
300 REM ASK FOR THE SPECIMEN #.
310 INPUT"SPECIMEN # ";SP
320 REM READ IN DATA FOR THE SATURATION.
330 REM
335 IF SP>13 THEN 350
340 ON SP GOSUB9000,9001,9002,9003,9004,9005,9006,9007,9008,9009,9010,9011,9012
345 GO TO 370
350 J=SP-13
360 ON J GOSUB9013,9014,9015,9016,9017,9018,9019,9020,9021,9022,9023,9024,9025
370 REM
380 INPUT#3,DU
390 INPUT#3,TM
400 INPUT#3,DM
410 FOR DD=1 TO 20
420 INPUT#3,P(DD),M(DD),S(DD)
430 NEXT DD
440 CLOSE3
441 IF SP=3 THEN S(10)=0:REM MODIFICATION FOR REJECTED DATA POINTS.
442 IF SP=4 THEN S(18)=0
443 IF SP=5 THEN S(7)=0
444 IF SP=7 THEN S(3)=0

```



```

445 IF SP=8 THEN S(7)=0
446 IF SP=9 THEN S(9)=0
447 IF SP=10 THEN S(17)=0
448 IF SP=10 THEN S(1)=.811
449 IF SP=12 THEN S(8)=0
450 IF SP=13 THEN S(1)=0
451 IF SP=16 THEN S(13)=0
452 IF SP=17 THEN S(12)=0
460 REM
470 REM SET THE ANGULAR VELOCITY W.
480 IF SP<=6 THEN W=500*2*PI
490 IF (SP>7)AND(SP<=12) THEN W=580*2*PI
500 IF SP>13 THEN W=360*2*PI
510 REM
520 REM
530 REM CALCULATE THE CAPILLARY PRESSURES
540 FOR DD=1 TO 20
550 IF (S(DD)<=0) THEN 570
560 PC(DD)=(W/60)^2*P(DD)*(24-(P(DD)/2))
570 NEXT DD
580 REM
590 REM
600 REM START CALCULATING THE LOG. OF DATA.
610 REM
620 FOR DD=1 TO 20
630 IF (S(DD)<=0) THEN 660
640 Z(DD)=LOG(PC(DD))
650 T(DD)=LOG(S(DD))
660 NEXT DD
670 REM
680 REM
690 REM START CALCULATING THE POWER EQUATION.
695 N=0:Z2=0:ZT=0:RT=0:S2=0:T2=0:DT=0:D=0:C=0:L1=0:L2=0:L3=0:L4=0:L5=0:L6=0
696 L7=0:L8=0
700 FOR I=NS(SP) TO NE(SP)
710 IF (S(I)<=0) THEN 770
711 L1=L1+S(I)
712 L2=L2+S(I)^2
713 L3=L3+PC(I)
714 L4=L4+S(I)^3
715 L5=L5+PC(I)*S(I)
716 L6=L6+S(I)^4
717 L7=L7+PC(I)*(S(I)^2)
718 L8=L8+PC(I)^2
720 ZT=ZT+Z(I)*T(I)
730 RT=RT+T(I)
740 S2=S2+Z(I)
750 T2=T2+T(I)^2
755 Z2=Z2+Z(I)^2
760 N=N+1
770 NEXT I
771 REM QUADRATIC EQUATION CALCULATION.
772 NU=L2*L3*(L6^2)-L3*L6*(L4^2)-L5*L1*(L6^2)+L4*L7*L6*L1-L7*L6*L2^2+L2*L4*L5*L6
773 DE=N*L2*(L6^2)-N*L6*(L4^2)-(L1^2)*(L6^2)+2*L2*L4*L1*L6-L6*(L2^3):K0=NU/DE
774 NU=L5*L6-L4*L7-K0*(L1*L6-L4*L2):DE=L2*L6-(L4^2):K1=NU/DE:NU=L7-K0*L2-K1*L4
775 K2=NU/L6:NU=0:DE=0
776 FOR DD=NS(SP) TO NE(SP):IF S(DD)<=0 THEN 778
777 NU=NU+(PC(DD)-(K0+K1*S(DD)+K2*(S(DD)^2)))^2:DE=DE+(PC(DD)-L8/N)^2
778 NEXT DD
779 R5=(ABS(1-NU/DE))^1.5:REM NOW START THE POWER EQUATION CALCULATION.
780 DT=RT^2
785 DZ=S2^2
790 D=(N*ZT-RT*S2)/(N*T2-DT)
800 C=EXP(S2/N-(D*RT)/N)
810 R=(N*ZT-S2*RT)/(N*T2-DT)^1.5*(N*Z2-DZ)^1.5)
812 REM CALCULATE THE LINEAR EQ. FOR THE FULL SATURATION TO THE STARTING POINT

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813 REM OF THE POWER EQUATION.
814 NR=0:SR=0:SS=0:PS=0:S2=0:DS=0:R2=0:DR=0:A=0:B=0:RI=NS(SP)
815 IF NS(SP)=1 THEN RI=2
816 FOR I=1 TO RI
817 IF (S(I)<0) THEN 830
819 SR=SR+PC(I)
820 REM
821 SS=SS+S(I)
823 PS=PS+PC(I)*S(I)
825 S2=S2+S(I)^2
827 R2=R2+PC(I)^2
829 NR=NR+1
830 NEXT I
832 DS=SS^2
834 DR=SR^2
836 B=(NR*PS-SS*SR)/(NR*S2-DS)
838 A=SR/NR-B*(SS/NR)
839 R1=(NR*PS-SS*SR)/((NR*S2-DS)^.5)*((NR*R2-DR)^.5))
840 REM PRINT OUT THE RESULTS
850 OPEN#4,CMD4
860 PRINT#4,"SPECIMEN #";SP
865 PRINT#4,"*****"
866 IF SP>9 THEN 868
867 PRINT#4,"DATA FILE IS'0";SP;"PCOFSAT QUAD'";GO TO 869
868 PRINT#4,"DATA FILE IS'";SP;"PCOFSAT QUAD'"
869 PRINT#4,
870 PRINT#4,"CAPILLARY PRESSURE AS A FUNCTION OF SATURATION."
875 PRINT#4,"RANGE OF SATURATION IS 0.0<S<1.0"
877 PRINT#4,"UNITS OF CAPILLARY PRESSURE IS IN DYNE/CM^2"
880 PRINT#4,"(CAP. PRESS.)=C*(SAT.)^D"
890 PRINT#4,"WHERE C=";C;" & D=";D
900 PRINT#4,
910 PRINT#4,"PC=";C;"* S ^";D
911 PRINT#4,"QUADRATIC EQUATION FORM IS PC=K0+K1*S+K2*(S^2) WHERE:"
912 PRINT#4,"K0=";K0;"K1=";K1;"K2=";K2
920 PRINT#4,
930 PRINT#4,"THE RANGE OF POSITIONS USED IS[";NS(SP);";";NE(SP);"]"
940 PRINT#4,"CORRELATION COEFFICIENT OF THE CURVE FIT FOR POWER EQ. IS";R
942 PRINT#4,"CORRELATION COEFFICIENT FOR THE QUADRATIC EQ. IS";R5
943 PRINT#4,
944 PRINT#4,"FOR POSITION RANGE OF [1,";RI;"]"
945 PRINT#4,"NOTE: AT POSITION 1 WE HAVE FULL SATURATION."
946 PRINT#4,
947 PRINT#4,"LINEAR EQ. OF FORM PC=A+B*S"
948 PRINT#4,"WHERE A=";A;" & B=";B;PRINT#4,"PC=";A;"+";B;"* S";PRINT#4,
949 PRINT#4,"CORRELATION COEFFICIENT FOR THE LINEAR EQUATION PART IS";R1
950 PRINT#4,"THE CLOSER ABS. VALUE OF R IS TO 1 THE BETTER CURVE FIT WE HAVE."
950 PRINT#4,"*****"
970 PRINT#4,
980 PRINT#4,"":CLOSE4
990 REM
1000 C$=","
1010 REM
1020 IF SP>13 THEN 1050
1030 ON SP GOSUB9100,9101,9102,9103,9104,9105,9106,9107,9108,9109,9110,9111,9112
1040 GO TO 1100
1050 ON J GOSUB9113,9114,9115,9116,9117,9118,9119,9120,9121,9122,9123,9124,9125
1060 REM
1070 REM
1080 REM
1090 REM SAVE RESULTS ON DISK IN DRIVE 0
1100 PRINT#3,SPCHR$(13);REM SPECIMEN #
1110 PRINT#3,NS(SP)CHR$(13);REM LOWER RANGE OF POSITIONS USED.
1120 PRINT#3,NE(SP)CHR$(13);REM UPPER RANGE.
1130 PRINT#3,CCHR$(13);REM PC=C*S^D
1140 PRINT#3,DCHR$(13)

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1150 PRINT#3,RCHR$(13):REM CORRELATION COEFFICIENT.
1160 PRINT#3,NCHR$(13):REM # OF POINTS USED.
1162 PRINT#3,ACHR$(13):REM PC=A+B*S
1164 PRINT#3,BCHR$(13)
1166 PRINT#3,R1CHR$(13):REM CORRELATION COEFFICIENT OF LINEAR EQUATION.
1168 PRINT#3,NRCHR$(13):REM # OF POINTS USED FOR LINEAR EQUATION.
1169 PRINT#3,K0CHR$(13):REM QUAD. EQ. & CORRELATION COEFF.
1171 PRINT#3,K1CHR$(13)
1173 PRINT#3,K2CHR$(13)
1175 PRINT#3,R5CHR$(13)
1177 CLOSE#3
1180 REM
1190 REM
1200 REM
1210 INPUT"DO YOU WANT ANOTHER SPECIMEN Y/N";A$
1220 IF A$="Y" THEN 300
1230 END
9000 OPEN3,8,9,"1:01MS08,SEQ,READ":RETURN
9001 OPEN3,8,9,"1:02MS08,SEQ,READ":RETURN
9002 OPEN3,8,9,"1:03MS08,SEQ,READ":RETURN
9003 OPEN3,8,9,"1:04MS08,SEQ,READ":RETURN
9004 OPEN3,8,9,"1:05MS08,SEQ,READ":RETURN
9005 OPEN3,8,9,"1:06MS08,SEQ,READ":RETURN
9006 OPEN3,8,9,"1:07MS09,SEQ,READ":RETURN
9007 OPEN3,8,9,"1:08MS09,SEQ,READ":RETURN
9008 OPEN3,8,9,"1:09MS09,SEQ,READ":RETURN
9009 OPEN3,8,9,"1:10MS09,SEQ,READ":RETURN
9010 OPEN3,8,9,"1:11MS09,SEQ,READ":RETURN
9011 OPEN3,8,9,"1:12MS09,SEQ,READ":RETURN
9012 OPEN3,8,9,"1:13MS11,SEQ,READ":RETURN
9013 OPEN3,8,9,"1:14MS11,SEQ,READ":RETURN
9014 OPEN3,8,9,"1:15MS11,SEQ,READ":RETURN
9015 OPEN3,8,9,"1:16MS11,SEQ,READ":RETURN
9016 OPEN3,8,9,"1:17MS11,SEQ,READ":RETURN
9017 OPEN3,8,9,"1:18MS11,SEQ,READ":RETURN
9100 OPEN3,8,9,"0:01PCOFSAT QUAD,SEQ,WRITE":RETURN
9101 OPEN3,8,9,"0:02PCOFSAT QUAD,SEQ,WRITE":RETURN
9102 OPEN3,8,9,"0:03PCOFSAT QUAD,SEQ,WRITE":RETURN
9103 OPEN3,8,9,"0:04PCOFSAT QUAD,SEQ,WRITE":RETURN
9104 OPEN3,8,9,"0:05PCOFSAT QUAD,SEQ,WRITE":RETURN
9105 OPEN3,8,9,"0:06PCOFSAT QUAD,SEQ,WRITE":RETURN
9106 OPEN3,8,9,"0:07PCOFSAT QUAD,SEQ,WRITE":RETURN
9107 OPEN3,8,9,"0:08PCOFSAT QUAD,SEQ,WRITE":RETURN
9108 OPEN3,8,9,"0:09PCOFSAT QUAD,SEQ,WRITE":RETURN
9109 OPEN3,8,9,"0:10PCOFSAT QUAD,SEQ,WRITE":RETURN
9110 OPEN3,8,9,"0:11PCOFSAT QUAD,SEQ,WRITE":RETURN
9111 OPEN3,8,9,"0:12PCOFSAT QUAD,SEQ,WRITE":RETURN
9112 OPEN3,8,9,"0:13PCOFSAT QUAD,SEQ,WRITE":RETURN
9113 OPEN3,8,9,"0:14PCOFSAT QUAD,SEQ,WRITE":RETURN
9114 OPEN3,8,9,"0:15PCOFSAT QUAD,SEQ,WRITE":RETURN
9115 OPEN3,8,9,"0:16PCOFSAT QUAD,SEQ,WRITE":RETURN
9116 OPEN3,8,9,"0:17PCOFSAT QUAD,SEQ,WRITE":RETURN
9117 OPEN3,8,9,"0:18PCOFSAT QUAD,SEQ,WRITE":RETURN
9118 OPEN3,8,9,"0:19PCOFSAT QUAD,SEQ,WRITE":RETURN
9119 OPEN3,8,9,"0:20PCOFSAT QUAD,SEQ,WRITE":RETURN
9120 OPEN3,8,9,"0:21PCOFSAT QUAD,SEQ,WRITE":RETURN
9121 OPEN3,8,9,"0:22PCOFSAT QUAD,SEQ,WRITE":RETURN
9122 OPEN3,8,9,"0:23PCOFSAT QUAD,SEQ,WRITE":RETURN
9123 OPEN3,8,9,"0:24PCOFSAT QUAD,SEQ,WRITE":RETURN
9124 OPEN3,8,9,"0:25PCOFSAT QUAD,SEQ,WRITE":RETURN
9125 OPEN3,8,9,"0:26PCOFSAT QUAD,SEQ,WRITE":RETURN
READY.

```

READY.

```

10 REM*****
20 REM*
30 REM* SATURATION AS A FUNCTION OF *
40 REM* LOCATION. *
42 REM* *
43 REM* F 2 *
44 REM* S=E*Z , S=K0+K1*Z+K2*Z *
45 REM* S=A+B*Z *
50 REM* *
60 REM* FARID FIROOZMANDI *
70 REM* DECEMBER 31, 1984 *
80 REM* *
90 REM*****
100 REM
110 REM
120 REM
130 REM
140 REM THIS PROGRAM READS IN DATA FROM
150 REM DISK FOR THE SATURATION LEVEL OF
160 REM EACH SPECIMEN AT EACH RUN, AND
170 REM THEN USING THIS DATA CALCULATES
180 REM THREE EQUATIONS DESCRIBING SATURATION
190 REM AS A FUNCTION OF LOCATION.
200 REM
210 REM THE DATA DISK SHOULD BE IN DRIVE
220 REM 1, AND THE DISK ON WHICH THE
230 REM PARAMETERS OF THE EQUATIONS ARE
240 REM TO BE SAVED SHOULD BE IN DRIVE 0.
242 REM
243 REM MODIFICATIONS TO BE DONE FOR DIFFERENT SPECIMENS.
244 REM
245 REM CORRECT LINES 9000 TO 9012 FOR SPECIMEN #: '01'0000
246 REM
247 REM CORRECT LINE 1590 FOR SPECIMEN # : '01'00FLO
250 REM
260 DIM NS(18),NE(18),E(20),F(20),G(20),H(20),P(20),K(20),S(20),Z(20),T(20)
262 DIM R(20),R1(20),TH(20),DH(20),K0(20),K1(20),K2(20),F0(20)
270 REM ENTER THE STARTING AND ENDING POINTS.
280 NS(1)=4:NE(1)=20:NS(2)=4:NE(2)=18
290 NS(3)=1:NE(3)=20:NS(4)=11:NE(4)=20
300 NS(5)=7:NE(5)=19:NS(6)=7:NE(6)=20
310 NS(7)=4:NE(7)=15:NS(8)=6:NE(8)=15
320 NS(9)=1:NE(9)=20:NS(10)=4:NE(10)=20
330 NS(11)=2:NE(11)=18:NS(12)=3:NE(12)=18
340 NS(13)=7:NE(13)=20:NS(14)=7:NE(14)=13
350 NS(15)=5:NE(15)=14:NS(16)=5:NE(16)=13
360 NS(17)=4:NE(17)=16:NS(18)=7:NE(18)=20
370 REM
380 REM ASK FOR THE SPECIMEN #.
390 REM
400 INPUT "SPECIMEN #";SP
410 REM READ IN DATA FOR THE SATURATION.
420 REM
430 REM SET THE # OF FILES FOR THE SPECIMEN.
440 IF SP<=6 THEN RN=9
450 IF SP>=7 AND SP<=12 THEN RN=10
460 IF SP>=13 THEN RN=12
470 REM
480 REM
490 REM
500 FOR I=1 TO RN

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889 TCI)=EXP(SZ/N/(F(I)*K1)/N)
890 R(I)=(N*ZT-SZ*RT)/((N*T2-DT)*.5)*((N*Z2-DZ)*.5)
891 REM
892 REM QUADRATIC EQUATION CALCULATION.
893 NU=L2*L3*(L6+2)-L3*L6*(L4+2)-L5*L1*(L6+2)+L4*L7*L6*L1-L7*L6*L2+L2*L4*L5*L6
894 DE=N*L2*(L6+2)-N*L6*(L4+2)-(L1+2)*(L6+2)+2*L2*L4*L1+L6-L6*(L2+3)
895 K0(I)=NU/DE
896 REM
897 NU=L5*L6-L4*L7-K0(I)*(L1*L6-L4*L2)
898 DE=L2*L6-(L4+2)
899 K1(I)=NU/DE
900 REM
901 NU=L7-K0(I)*L2-K1(I)*L4
902 K2(I)=NU/L6
903 REM CORRELATION COEFFICIENT CALCULATION.
904 NU=0;DE=0
905 FOR DD=NS(SP) TO NE(SP)
906 IF S(DD)<=0 THEN 908
907 NU=NU+(S(DD)-(K0(I)+K1(I)*P(DD)+K2(I)*(P(DD)+2)))^2;DE=DE+(S(DD)-LS/N)^2
908 NEXT DD
909 R2(I)=(ABS(1-NU/DE))^.5
910 REM CALCULATE THE LINEAR EQ. FOR THE FULL SATURATION TO THE STARTING POINT
920 REM OF THE POWER EQ.
930 REM
940 HR=0;SR=0;SS=0;PS=0;S2=0;DS=0;R2=0;DR=0;RI=NS(SP)
950 IF NS(SP)=1 THEN RI=2
960 FOR DD=1 TO RI
970 IF S(DD)<=0 THEN 1040
980 SR=SR+S(DD)
990 SS=SS+P(DD)
1000 PS=PS+S(DD)*P(DD)
1010 S2=S2+P(DD)^2
1020 R2=R2+S(DD)^2
1030 HR=HR+1
1040 NEXT DD
1050 DS=SS^2
1060 DR=SR^2
1070 REM
1080 H(I)=(HR*PS-SS*SR)/(HR*S2-DS)
1090 G(I)=SR/HR-H(I)*(SS/HR)
1100 R1(I)=(HR*PS-SS*SR)/((HR*S2-DS)*.5)*((HR*R2-DR)*.5)
1110 REM
1120 REM
1130 REM
1140 REM END OF CALCULATION FOR A RUN.
1150 NEXT I
1160 REM
1170 REM
1180 REM
1190 REM
1200 REM PRINT OUT THE RESULTS.
1210 OPEN#4,CMD4
1220 PRINT#4,"SPECIMEN #";SP
1230 PRINT#4,"*****"
1240 PRINT#4,"*****"
1250 IF SP>9 THEN 1270
1260 PRINT#4," DATA FILE IS '0'";SP;"SOFLOC":60 TO 1260
1270 PRINT#4," DATA FILE IS '0'";SP;"SOFLOC"
1280 PRINT#4,
1290 PRINT#4,"SATURATION AS A FUNCTION OF LOCATION. "
1300 PRINT#4,"RANGE OF LOCATION IS 0<=Z<=8 CENTIMETER. "
1310 PRINT#4,"RANGE OF SATURATION IS 0<=S<=1. "
1320 PRINT#4,"THE EQUATION OF S=F(Z) IS DEVIDED BETWEEN TWO REGIONS. "
1330 PRINT#4,"THE FIRST PART (Z=0 & UP) IS A LINEAR EQUATION S=G+H*Z. "
1340 PRINT#4,"THE SECOND PART IS A POWER EQUATION S=E*(Z+1)^2, OR A QUADRATIC "
1350 PRINT#4,"EQUATION S=K0+K1*Z+K2*Z^2. "

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1360 PRINT#4,"THE CORRELATION COEFFICIENT  $-1 \leq R \leq 1$  IS A MEASURE OF GOODNESS OF FIT."
1370 PRINT#4,"FIT."
1380 PRINT#4,"THE CLOSER ABS(R) IS TO 1 THE BETTER FIT WE HAVE."
1390 PRINT#4,""
1400 REM
1410 PRINT#4,
1420 PRINT#4,"LINEAR EQ.," "POWER EQ.," "QUADRATIC EQ."
1430 PRINT#4,"S=G+H*Z", "S=E*(Z+F)", "S=K0+K1*Z+K2*Z^2"
1440 PRINT#4,"SPECIMEN #";SP
1450 PRINT#4,
1460 PRINT#4,"*****"
1470 FOR I=1 TO RN
1480 REM
1490 PRINT#4,"RUN #";I-1
1500 PRINT#4,"LINEAR G=";G(I); " H=";H(I); " R=";R(I)
1510 PRINT#4,"POWER E=";E(I); " F=";F(I); " R=";R(I)
1512 PRINT#4,"QUADRATIC K0=";K0(I); "K1=";K1(I); "K2=";K2(I); "R=";R2(I)
1520 NEXT I
1530 PRINT#4,"*****"
1540 REM
1550 PRINT#4;CLOSE4
1560 REM
1570 REM
1575 C#=","
1580 REM SAVE DATA ON DISK IN DRIVE 0.
1590 OPEN3,8,9,"0:01SOFLOC,SEQ,WRITE"
1600 PRINT#3,SPCHR$(13);REM SPECIMEN #
1610 PRINT#3,NS(SP)CHR$(13);REM LOWER RANGE OF POSITIONS USED.
1620 PRINT#3,NE(SP)CHR$(13);REM UPPER RANGE.
1630 FOR I=1 TO RN
1632 PRINT#3,TR(I)CHR$(13);REM TIME OF RUN
1634 PRINT#3,DM(I)CHR$(13);REM MASS OF SPECIMEN AT THAT TIME.
1640 PRINT#3,G(I)CHR$(13)
1642 PRINT#3,H(I)CHR$(13)
1644 PRINT#3,R1(I)CHR$(13)
1646 PRINT#3,E(I)CHR$(13)
1648 PRINT#3,F(I)CHR$(13)
1650 PRINT#3,R(I)CHR$(13)
1652 PRINT#3,K0(I)CHR$(13)
1654 PRINT#3,K1(I)CHR$(13)
1656 PRINT#3,K2(I)CHR$(13)
1658 PRINT#3,R2(I)CHR$(13)
1660 NEXT I
1670 REM
1680 REM
1690 REM
1700 CLOSE3
1800 END
9000 OPEN3,8,9,"1:01MS00,SEQ,READ":RETURN
9001 OPEN3,8,9,"1:01MS01,SEQ,READ":RETURN
9002 OPEN3,8,9,"1:01MS02,SEQ,READ":RETURN
9003 OPEN3,8,9,"1:01MS03,SEQ,READ":RETURN
9004 OPEN3,8,9,"1:01MS04,SEQ,READ":RETURN
9005 OPEN3,8,9,"1:01MS05,SEQ,READ":RETURN
9006 OPEN3,8,9,"1:01MS06,SEQ,READ":RETURN
9007 OPEN3,8,9,"1:01MS07,SEQ,READ":RETURN
9008 OPEN3,8,9,"1:01MS08,SEQ,READ":RETURN
9009 OPEN3,8,9,"1:01MS09,SEQ,READ":RETURN
9010 OPEN3,8,9,"1:01MS10,SEQ,READ":RETURN
9011 OPEN3,8,9,"1:01MS11,SEQ,READ":RETURN
9012 OPEN3,8,9,"1:01MS12,SEQ,READ":RETURN
READY.

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READY.

SEARCHING FOR #0

READY.

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30 REM* UNSATURATED PERMEABILITY CALCULATION. K<S<L>>,MODIFIED VERSION,SP 17010
60 REM* FARID PIROOZMANDI, JANUARY 2, 1985. POWER EQUATION USED FOR CURVE FITS
110 REM MODIFIED VERSION WITH S'(<0>), AND C<S<0>> FOR STARTING POINT <0>.
130 REM THIS PROGRAM READS IN DATA FOR CAPILLARY PRESSURE AS A FUNCTION OF SAT.
140 REM AND ALSO SATURATION AS A FUNCTION OF LOCATION, AND SAT. AND MOISTURE
150 REM FILES THEN IT WILL ASK FOR THE SPECIMEN #, THE UPPER LIMIT ON LOCATION,
160 REM AND THE FULLY SATURATED PERMEABILITY VALUE. AFTER THE DATA IS INPUT,
170 REM THE COMPUTER WILL CALCULATE THE BODY FORCES B<L>, AND S<0>, DERIVATIVE
180 REM OF SATURATION S'(<L>), & S'(<0>), DERIVATIVE OF CAPILLARY PRESSURE C<S<L>>,
190 REM C<S<0>> & THE INTEGRAL OF SATURATION TO CALCULATE THE REMOVED MOISTURE
200 REM AT THE END PROG. WILL CALCULATE THE UNSATURATED PERMEABILITY OF SAMPLE.
340 REM PUT THE DATA DISK FOR MOISTURE & SATURATION IN DRIVE # 1. THE DATA DISK
350 REM FOR S<Z>, & PC<S> IN DRIVE #0.
400 DIM K<3<18>),K4<18>),K5<18>),TM<13>),DM<13>),P<40>),S<40>),UK<20>),SS<20>),NE<18>
405 DIM NS<18>
410 NE<1>=20:NE<2>=18:NE<3>=20:NE<4>=20:NS<1>=4:NS<2>=4:NS<3>=1:NS<4>=11
420 NE<5>=19:NE<6>=20:NE<7>=15:NE<8>=15:NS<5>=7:NS<6>=7:NS<7>=4:NS<8>=6:NS<9>=1
430 NE<9>=20:NE<10>=20:NE<11>=18:NE<12>=18:NS<10>=4:NS<11>=2:NS<12>=3:NS<13>=7
440 NE<13>=20:NE<14>=13:NE<15>=14:NE<16>=13:NS<14>=7:NS<15>=5:NS<16>=5:NS<17>=4
450 NE<17>=16:NE<18>=20:NS<18>=7
500 REM ASK FOR DATA TO BE PROVIDED BY THE USER.
510 INPUT"SPECIMEN # (<1 TO 10>):";SP:IF SP<=6 THEN RN=9
511 IF (SP=7)AND(SP<=12) THEN RN=10
512 IF SP=13 THEN RN=12
514 FOR E=1 TO 20:SS<E>=0:UK<E>=0:NEXT E
520 PRINT"UPPER LOCATION RANGE (<L>):";NS<SP>:"TO";NE<SP>";INPUT L
530 INPUT"UNSATURATED PERMEABILITY (DARCY'S)":PE:PE=PE*(9.87E-9)
540 REM READ IN DATA FOR PC<S>, & S<Z>.
550 SR=SP-13:IF SP>13 THEN 580
560 ON SP GOTO 9001,9002,9003,9004,9005,9006,9007,9008,9009,9010,9011,9012,9013
570 GO TO 590
580 ON SR GOTO 9014,9015,9016,9017,9018
590 REM START READING THE DATA FOR PC<S>).REFERED TO.
600 INPUT#3,D
610 INPUT#3,D
620 INPUT#3,D
630 INPUT#3,K0
640 INPUT#3,K1
650 INPUT#3,D
660 INPUT#3,D
670 INPUT#3,D
680 INPUT#3,D
690 INPUT#3,D
700 INPUT#3,D
710 INPUT#3,D
712 INPUT#3,D
714 INPUT#3,D
716 INPUT#3,D
720 CLOSE3:REM READ IN DATA FOR S<Z>.
730 IF SP>13 THEN 770
750 ON SP GOTO 9101,9102,9103,9104,9105,9106,9107,9108,9109,9110,9111,9112,9113
760 GO TO 780
770 ON SR GOTO 9114,9115,9116,9117,9118,
780 REM READ IN DATA FOR S<Z>).REFERED TO.
790 INPUT#3,SP
800 INPUT#3,D
810 INPUT#3,D
820 FOR I=1 TO RN
830 INPUT#3,TM<I>
840 INPUT#3,DM<I>
850 INPUT#3,D

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```

850 INPUT#3,D
860 INPUT#3,D
870 INPUT#3,D
880 INPUT#3,K3(I)
890 INPUT#3,K4(I)
900 INPUT#3,D
910 INPUT#3,D:INPUT#3,D:INPUT#3,D:INPUT#3,D
920 NEXT I:CLOSE3:REM START THE MAIN CALCULATION.
922 IF SP=15 THEN TM(7)=9.8
1030 FOR I=1 TO RN-1
1050 IF SP<=6 THEN W=500
1060 IF SP>=7 AND SP<=12 AND I<=6 THEN W=845
1070 IF SP>=7 AND SP<=12 AND I>=7 THEN W=580
1080 IF SP>=13 AND SP<=18 AND I<=8 THEN W=200
1090 IF SP>=13 AND SP<=18 AND I>=9 THEN W=360
1130 REM PASS OVER THE RUNS IN WHICH THE W CHANGES.
1170 IF SP>=7 AND SP<=12 AND I=6 THEN TM(6)=0:W=580:REM CHANGE OF SPEED RUNS.
1180 IF SP>=13 AND SP<=18 AND I=8 THEN TM(8)=0:W=360:REM CHANGE OF SPEED RUNS.
1200 IF SP>13 THEN 1230
1210 ON SP GOTO 9200,9250,9300,9350,9400,9450,9500,9550,9600,9650,9700,9750,9800
1220 GO TO 1240
1230 ON SR GOTO 9850,9900,9950,10000,10050
1240 REM REFERED TO.
1241 IF SP=1 AND I=1 THEN S(1)=.795
1242 IF SP=2 AND I=1 THEN S(1)=.740
1243 IF SP=3 THEN S(10)=(S(9)+S(11))/2:S(30)=(S(29)+S(31))/2
1244 IF SP=4 THEN S(18)=(S(17)+S(19))/2:S(38)=(S(37)+S(39))/2
1245 IF SP=6 AND I=4 THEN S(21)=.782
1246 IF SP=6 AND I=5 THEN S(1)=.782
1247 IF SP=6 AND I=6 THEN S(26)=.829
1248 IF SP=6 AND I=7 THEN S(6)=.829
1249 IF SP=7 THEN S(3)=(S(2)+S(1))/2:S(23)=(S(22)+S(24))/2
1250 IF SP=8 THEN S(7)=(S(6)+S(8))/2:S(27)=(S(26)+S(28))/2
1251 IF SP=9 THEN S(9)=(S(8)+S(10))/2:S(29)=(S(28)+S(30))/2
1252 IF SP=10 THEN S(17)=(S(16)+S(18))/2:S(37)=(S(36)+S(38))/2
1253 IF SP=10 AND I=8 THEN S(21)=.811
1254 IF SP=10 AND I=9 THEN S(1)=.811:S(21)=.811
1255 IF SP=10 AND I=10 THEN S(1)=.811
1256 IF SP=12 THEN S(8)=(S(7)+S(9))/2:S(28)=(S(27)+S(29))/2
1257 IF SP=13 THEN S(1)=S(2):S(21)=S(22)
1258 IF SP=14 AND I=1 THEN S(1)=.961
1259 IF SP=16 THEN S(13)=(S(12)+S(14))/2:S(33)=(S(32)+S(34))/2
1260 IF SP=16 AND I=1 THEN S(1)=.983
1261 IF SP=17 THEN S(12)=(S(11)+S(13))/2:S(32)=(S(31)+S(33))/2
1262 IF SP=17 AND I=1 THEN S(1)=.913
1263 IF SP=17 AND I=7 THEN S(21)=.913
1264 IF SP=17 AND I=8 THEN S(1)=.913
1265 IF SP=18 AND I=3 THEN S(21)=.968
1266 IF SP=18 AND I=4 THEN S(1)=.968
1267 IF SP=5 THEN S(7)=(S(6)+S(8))/2:S(27)=(S(26)+S(28))/2
1269 REM CALCULATE THE BODY FORCES B(L), AND B(0).
1270 B0=((2*pi*W/60)*t2)*(24-P(NS(SP)))
1280 BL=((2*pi*W/60)*t2)*(24-P(L))
1300 REM CALCULATE THE S'(L), AND S'(0).
1310 SL=K3(I)*K4(I)*(P(L)+K4(I)-1.0)+(K3(I+1)*K4(I+1)*(P(L)+K4(I+1)-1.0))
1312 SL=SL/2
1315 S0=(K3(I)*K4(I)*(P(NS(SP))+K4(I)-1.0))
1317 S0=(S0+K3(I+1)*K4(I+1)*(P(NS(SP))+K4(I+1)-1.0))/2
1330 REM CALCULATE THE C(S(L)), AND C(S(0)).
1350 SS(I)=K3(I)*(P(L)+K4(I))+K3(I+1)*(P(L)+K4(I+1))
1360 SS(I)=(SS(I)/2):CL=K0*K1*(SS(I)+K1-1.0)
1385 SX=(S(NS(SP))+S(NS(SP)+20))/2
1386 C0=K0*K1*(SX+K1-1.0)
1400 REM CALCULATE THE INTEGRAL PART.
1410 SN=0:SM=0
1420 FOR DD=NS(SP):TOL:SN=SN+S(DD):NEXTOO
1450 FOR DD=20:NS(SP):TOL:SM=SM+S(DD):NEXTOO

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1400 FOR DD=20713057710 TO 20713105075000/INCR100
1500 SZ=((SM-SN)*.4048)/((TH(I+1)-TH(I))*24*3600):REM TIME IN SECONDS.
1530 REM CALCULATE THE UNSATURATED PERMEABILITY.
1540 UK(I)=(PE*(CO*SO-B0)-(1.002E-2)*.63*SZ)/(CL*SL-BL)
2000 NEXT I
2030 REM PRINT OUT THE RESULTS.
2060 OPEN4,4:CMD4:PRINT#4,"UNSATURATED PERMEABILITY VALUES USING SPECIMEN #";SP
2070 PRINT#4,"UPPER LOCATION RANGE IS";L
2080 PRINT#4,"SATURATED PERMEABILITY VALUE IS";PE/(9.87E-9);"DARCY"
2090 PRINT#4,"*****"
2095 PRINT#4,"SATURATION","PERMEABILITY (DARCY)","K(S)/K(S0)"
2100 FOR DD=1 TO RN-1
2105 IF SS(DD)=0 THEN 2130
2110 PRINT#4,SS(DD),
2112 IF SS(DD)=0 THEN 2130
2120 PRINT#4,UK(DD)/(9.87E-9),
2125 PRINT#4,UK(DD)/PE
2130 NEXT DD
2140 PRINT#4,"*****"
2150 PRINT#4:CLOSE4
2180 REM REDO THE CALCULATION WITH NEW PARAMETERS.
2190 PRINT"DO YOU WANT A NEW RUN Y/N":INPUT A$
2200 IF A$="Y" THEN 500
5000 END
9001 OPEN3,8,9,"0:01PCOFSAT QUAD,SEQ,READ":GO TO 590
9002 OPEN3,8,9,"0:02PCOFSAT QUAD,SEQ,READ":GO TO 590
9003 OPEN3,8,9,"0:03PCOFSAT QUAD,SEQ,READ":GO TO 590
9004 OPEN3,8,9,"0:04PCOFSAT QUAD,SEQ,READ":GO TO 590
9005 OPEN3,8,9,"0:05PCOFSAT QUAD,SEQ,READ":GO TO 590
9006 OPEN3,8,9,"0:06PCOFSAT QUAD,SEQ,READ":GO TO 590
9007 OPEN3,8,9,"0:07PCOFSAT QUAD,SEQ,READ":GO TO 590
9008 OPEN3,8,9,"0:08PCOFSAT QUAD,SEQ,READ":GO TO 590
9009 OPEN3,8,9,"0:09PCOFSAT QUAD,SEQ,READ":GO TO 590
9010 OPEN3,8,9,"0:10PCOFSAT QUAD,SEQ,READ":GO TO 590
9011 OPEN3,8,9,"0:11PCOFSAT QUAD,SEQ,READ":GO TO 590
9012 OPEN3,8,9,"0:12PCOFSAT QUAD,SEQ,READ":GO TO 590
9013 OPEN3,8,9,"0:13PCOFSAT QUAD,SEQ,READ":GO TO 590
9014 OPEN3,8,9,"0:14PCOFSAT QUAD,SEQ,READ":GO TO 590
9015 OPEN3,8,9,"0:15PCOFSAT QUAD,SEQ,READ":GO TO 590
9016 OPEN3,8,9,"0:16PCOFSAT QUAD,SEQ,READ":GO TO 590
9017 OPEN3,8,9,"0:17PCOFSAT QUAD,SEQ,READ":GO TO 590
9018 OPEN3,8,9,"0:18PCOFSAT QUAD,SEQ,READ":GO TO 590
9101 OPEN3,8,9,"0:01SOFLOC,SEQ,READ":GO TO 780
9102 OPEN3,8,9,"0:02SOFLOC,SEQ,READ":GO TO 780
9103 OPEN3,8,9,"0:03SOFLOC,SEQ,READ":GO TO 780
9104 OPEN3,8,9,"0:04SOFLOC,SEQ,READ":GO TO 780
9105 OPEN3,8,9,"0:05SOFLOC,SEQ,READ":GO TO 780
9106 OPEN3,8,9,"0:06SOFLOC,SEQ,READ":GO TO 780
9107 OPEN3,8,9,"0:07SOFLOC,SEQ,READ":GO TO 780
9108 OPEN3,8,9,"0:08SOFLOC,SEQ,READ":GO TO 780
9109 OPEN3,8,9,"0:09SOFLOC,SEQ,READ":GO TO 780
9110 OPEN3,8,9,"0:10SOFLOC,SEQ,READ":GO TO 780
9111 OPEN3,8,9,"0:11SOFLOC,SEQ,READ":GO TO 780
9112 OPEN3,8,9,"0:12SOFLOC,SEQ,READ":GO TO 780
9113 OPEN3,8,9,"0:13SOFLOC,SEQ,READ":GO TO 780
9114 OPEN3,8,9,"0:14SOFLOC,SEQ,READ":GO TO 780
9115 OPEN3,8,9,"0:15SOFLOC,SEQ,READ":GO TO 780
9116 OPEN3,8,9,"0:16SOFLOC,SEQ,READ":GO TO 780
9117 OPEN3,8,9,"0:17SOFLOC,SEQ,READ":GO TO 780
9118 OPEN3,8,9,"0:18SOFLOC,SEQ,READ":GO TO 780
9200 REM SPECIMEN #1 SATURATION AND MOISTURE CONTENT DATA INPUT.
9201 ONIGOSUB9203,9207,9211,9215,9219,9223,9227,9231
9202 GO TO 1240
9203 OPEN3,8,9,"1:01MS00,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9204 FORDD=1TO20:INPUT#3,P(DD),D,S(DD):NEXTDD:CLOSE3
9205 OPEN3,8,9,"1:01MS01,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9206 FORDD=21TO40:INPUT#3,P(DD),D,S(DD):NEXTDD:CLOSE3:RETURN

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9200 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9207 OPEN3,8,9,"1:01MS01,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9208 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9209 OPEN3,8,9,"1:01MS02,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9210 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9211 OPEN3,8,9,"1:01MS02,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9212 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9213 OPEN3,8,9,"1:01MS03,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9214 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9215 OPEN3,8,9,"1:01MS03,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9216 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9217 OPEN3,8,9,"1:01MS04,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9218 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9219 OPEN3,8,9,"1:01MS04,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9220 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9221 OPEN3,8,9,"1:01MS05,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9222 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9223 OPEN3,8,9,"1:01MS05,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9224 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9225 OPEN3,8,9,"1:01MS06,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9226 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9227 OPEN3,8,9,"1:01MS06,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9228 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9229 OPEN3,8,9,"1:01MS07,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9230 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9231 OPEN3,8,9,"1:01MS07,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9232 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9233 OPEN3,8,9,"1:01MS08,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9234 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9250 REM SPECIMEN #2 SATURATION AND MOISTURE CONTENT DATA INPUT.
9251 ONIGOSUB9253,9257,9261,9265,9269,9273,9277,9281
9252 GO TO 1240
9253 OPEN3,8,9,"1:02MS00,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9254 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9255 OPEN3,8,9,"1:02MS01,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9256 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9257 OPEN3,8,9,"1:02MS01,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9258 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9259 OPEN3,8,9,"1:02MS02,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9260 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9261 OPEN3,8,9,"1:02MS02,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9262 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9263 OPEN3,8,9,"1:02MS03,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9264 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9265 OPEN3,8,9,"1:02MS03,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9266 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9267 OPEN3,8,9,"1:02MS04,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9268 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9269 OPEN3,8,9,"1:02MS04,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9270 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9271 OPEN3,8,9,"1:02MS05,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9272 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9273 OPEN3,8,9,"1:02MS05,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9274 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9275 OPEN3,8,9,"1:02MS06,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9276 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9277 OPEN3,8,9,"1:02MS06,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9278 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9279 OPEN3,8,9,"1:02MS07,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9280 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9281 OPEN3,8,9,"1:02MS07,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9282 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9283 OPEN3,8,9,"1:02MS08,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9284 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9300 REM SPECIMEN #3 SATURATION AND MOISTURE CONTENT DATA INPUT.
9301 ONIGOSUB9303,9307,9311,9315,9319,9323,9327,9331
9302 GO TO 1240

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9302 GO TO 1270
9303 OPEN3,8,9,"1:03MS00,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9304 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9305 OPEN3,8,9,"1:03MS01,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9306 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9307 OPEN3,8,9,"1:03MS01,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9308 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9309 OPEN3,8,9,"1:03MS02,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9310 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9311 OPEN3,8,9,"1:03MS02,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9312 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9313 OPEN3,8,9,"1:03MS03,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9314 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9315 OPEN3,8,9,"1:03MS03,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9316 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9317 OPEN3,8,9,"1:03MS04,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9318 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9319 OPEN3,8,9,"1:03MS04,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9320 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9321 OPEN3,8,9,"1:03MS05,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9322 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9323 OPEN3,8,9,"1:03MS05,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9324 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9325 OPEN3,8,9,"1:03MS06,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9326 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9327 OPEN3,8,9,"1:03MS06,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9328 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9329 OPEN3,8,9,"1:03MS07,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9330 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9331 OPEN3,8,9,"1:03MS07,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9332 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9333 OPEN3,8,9,"1:03MS08,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9334 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9350 REM SPECIMEN #4 SATURATION AND MOISTURE CONTENT DATA INPUT.
9351 ONIGOSUB9353,9357,9361,9365,9369,9373,9377,9381
9352 GO TO 1240
9353 OPEN3,8,9,"1:04MS00,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9354 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9355 OPEN3,8,9,"1:04MS01,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9356 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9357 OPEN3,8,9,"1:04MS01,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9358 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9359 OPEN3,8,9,"1:04MS02,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9360 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9361 OPEN3,8,9,"1:04MS02,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9362 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9363 OPEN3,8,9,"1:04MS03,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9364 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9365 OPEN3,8,9,"1:04MS03,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9366 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9367 OPEN3,8,9,"1:04MS04,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9368 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9369 OPEN3,8,9,"1:04MS04,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9370 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9371 OPEN3,8,9,"1:04MS05,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9372 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9373 OPEN3,8,9,"1:04MS05,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9374 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9375 OPEN3,8,9,"1:04MS06,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9376 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9377 OPEN3,8,9,"1:04MS06,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9378 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9379 OPEN3,8,9,"1:04MS07,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9380 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9381 OPEN3,8,9,"1:04MS07,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9382 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9383 OPEN3,8,9,"1:04MS08,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D

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9383 OPEN3,8,9,"1:05MS00,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9384 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9400 REM SPECIMEN #5 SATURATION AND MOISTURE CONTENT DATA INPUT.
9401 ONIGOSUB9403,9407,9411,9415,9419,9423,9427,9431
9402 GO TO 1240
9403 OPEN3,8,9,"1:05MS00,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9404 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9405 OPEN3,8,9,"1:05MS01,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9406 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9407 OPEN3,8,9,"1:05MS01,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9408 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9409 OPEN3,8,9,"1:05MS02,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9410 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9411 OPEN3,8,9,"1:05MS02,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9412 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9413 OPEN3,8,9,"1:05MS03,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9414 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9415 OPEN3,8,9,"1:05MS03,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9416 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9417 OPEN3,8,9,"1:05MS04,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9418 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9419 OPEN3,8,9,"1:05MS04,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9420 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9421 OPEN3,8,9,"1:05MS05,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9422 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9423 OPEN3,8,9,"1:05MS05,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9424 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9425 OPEN3,8,9,"1:05MS06,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9426 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9427 OPEN3,8,9,"1:05MS06,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9428 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9429 OPEN3,8,9,"1:05MS07,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9430 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9431 OPEN3,8,9,"1:05MS07,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9432 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9433 OPEN3,8,9,"1:05MS08,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9434 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9450 REM SPECIMEN #6 SATURATION AND MOISTURE CONTENT DATA INPUT.
9451 ONIGOSUB9453,9457,9461,9465,9469,9473,9477,9481
9452 GO TO 1240
9453 OPEN3,8,9,"1:06MS00,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9454 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9455 OPEN3,8,9,"1:06MS01,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9456 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9457 OPEN3,8,9,"1:06MS01,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9458 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9459 OPEN3,8,9,"1:06MS02,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9460 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9461 OPEN3,8,9,"1:06MS02,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9462 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9463 OPEN3,8,9,"1:06MS03,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9464 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9465 OPEN3,8,9,"1:06MS03,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9466 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9467 OPEN3,8,9,"1:06MS04,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9468 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9469 OPEN3,8,9,"1:06MS04,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9470 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9471 OPEN3,8,9,"1:06MS05,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9472 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9473 OPEN3,8,9,"1:06MS05,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9474 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9475 OPEN3,8,9,"1:06MS06,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9476 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9477 OPEN3,8,9,"1:06MS06,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9478 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9479 OPEN3,8,9,"1:06MS07,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D

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9480 OPEN3,8,9,"1:06MS07,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9480 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9481 OPEN3,8,9,"1:06MS07,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9482 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9483 OPEN3,8,9,"1:06MS08,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9484 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9500 REM SPECIMEN #7 SATURATION AND MOISTURE CONTENT DATA INPUT.
9501 ONIGOSUB9503,9507,9511,9515,9519,9523,9527,9531,9535
9502 GO TO 1240
9503 OPEN3,8,9,"1:07MS00,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9504 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9505 OPEN3,8,9,"1:07MS01,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9506 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9507 OPEN3,8,9,"1:07MS01,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9508 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9509 OPEN3,8,9,"1:07MS02,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9510 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9511 OPEN3,8,9,"1:07MS02,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9512 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9513 OPEN3,8,9,"1:07MS03,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9514 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9515 OPEN3,8,9,"1:07MS03,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9516 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9517 OPEN3,8,9,"1:07MS04,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9518 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9519 OPEN3,8,9,"1:07MS04,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9520 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9521 OPEN3,8,9,"1:07MS05,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9522 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9523 OPEN3,8,9,"1:07MS05,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9524 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9525 OPEN3,8,9,"1:07MS06,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9526 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9527 OPEN3,8,9,"1:07MS06,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9528 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9529 OPEN3,8,9,"1:07MS07,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9530 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9531 OPEN3,8,9,"1:07MS07,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9532 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9533 OPEN3,8,9,"1:07MS08,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9534 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9535 OPEN3,8,9,"1:07MS08,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9536 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9537 OPEN3,8,9,"1:07MS09,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9538 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9550 REM SPECIMEN #8 SATURATION AND MOISTURE CONTENT DATA INPUT.
9551 ONIGOSUB9553,9557,9561,9565,9569,9573,9577,9581,9585
9552 GO TO 1240
9553 OPEN3,8,9,"1:08MS00,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9554 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9555 OPEN3,8,9,"1:08MS01,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9556 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9557 OPEN3,8,9,"1:08MS01,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9558 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9559 OPEN3,8,9,"1:08MS02,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9560 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9561 OPEN3,8,9,"1:08MS02,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9562 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9563 OPEN3,8,9,"1:08MS03,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9564 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9565 OPEN3,8,9,"1:08MS03,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9566 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9567 OPEN3,8,9,"1:08MS04,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9568 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9569 OPEN3,8,9,"1:08MS04,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9570 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9571 OPEN3,8,9,"1:08MS05,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D

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9571 OPEN3,8,9,"1:08MS05,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9572 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9573 OPEN3,8,9,"1:08MS05,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9574 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9575 OPEN3,8,9,"1:08MS06,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9576 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9577 OPEN3,8,9,"1:08MS06,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9578 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9579 OPEN3,8,9,"1:08MS07,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9580 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9581 OPEN3,8,9,"1:08MS07,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9582 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9583 OPEN3,8,9,"1:08MS08,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9584 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9585 OPEN3,8,9,"1:08MS08,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9586 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9587 OPEN3,8,9,"1:08MS09,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9588 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9600 REM SPECIMEN #9 SATURATION AND MOISTURE CONTENT DATA INPUT.
9601 ONIGOSUB9603,9607,9611,9615,9619,9623,9627,9631,9635
9602 GO TO 1240
9603 OPEN3,8,9,"1:09MS00,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9604 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9605 OPEN3,8,9,"1:09MS01,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9606 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9607 OPEN3,8,9,"1:09MS01,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9608 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9609 OPEN3,8,9,"1:09MS02,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9610 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9611 OPEN3,8,9,"1:09MS02,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9612 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9613 OPEN3,8,9,"1:09MS03,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9614 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9615 OPEN3,8,9,"1:09MS03,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9616 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9617 OPEN3,8,9,"1:09MS04,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9618 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9619 OPEN3,8,9,"1:09MS04,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9620 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9621 OPEN3,8,9,"1:09MS05,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9622 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9623 OPEN3,8,9,"1:09MS05,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9624 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9625 OPEN3,8,9,"1:09MS06,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9626 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9627 OPEN3,8,9,"1:09MS06,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9628 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9629 OPEN3,8,9,"1:09MS07,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9630 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9631 OPEN3,8,9,"1:09MS07,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9632 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9633 OPEN3,8,9,"1:09MS08,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9634 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9635 OPEN3,8,9,"1:09MS08,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9636 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9637 OPEN3,8,9,"1:09MS09,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9638 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9650 REM SPECIMEN #10 SATURATION AND MOISTURE CONTENT DATA INPUT.
9651 ONIGOSUB9653,9657,9661,9665,9669,9673,9677,9681,9685
9652 GO TO 1240
9653 OPEN3,8,9,"1:10MS00,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9654 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9655 OPEN3,8,9,"1:10MS01,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9656 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9657 OPEN3,8,9,"1:10MS01,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9658 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9659 OPEN3,8,9,"1:10MS02,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D

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9659 OPEN3,8,9,"1:10MS02,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9660 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9661 OPEN3,8,9,"1:10MS02,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9662 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9663 OPEN3,8,9,"1:10MS03,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9664 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9665 OPEN3,8,9,"1:10MS03,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9666 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9667 OPEN3,8,9,"1:10MS04,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9668 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9669 OPEN3,8,9,"1:10MS04,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9670 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9671 OPEN3,8,9,"1:10MS05,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9672 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9673 OPEN3,8,9,"1:10MS05,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9674 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9675 OPEN3,8,9,"1:10MS06,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9676 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9677 OPEN3,8,9,"1:10MS06,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9678 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9679 OPEN3,8,9,"1:10MS07,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9680 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9681 OPEN3,8,9,"1:10S07,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9682 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9683 OPEN3,8,9,"1:10MS08,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9684 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9685 OPEN3,8,9,"1:10MS08,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9686 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9687 OPEN3,8,9,"1:10MS09,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9688 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
READY.

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READY.

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30 REM* UNSATURATED PERMEABILITY CALCULATION. K(S<L>), MODIFIED VERSION.
60 REM* FARID PIROOZMANDI, JANUARY 7, 1985. POWER EQUATION USED FOR CURVE FITS
110 REM MODIFIED VERSION WITH S'(0), AND C(S<0>) FOR STARTING POINT C> 0.
130 REM THIS PROGRAM READS IN DATA FOR CAPILLARY PRESSURE AS A FUNCTION OF SAT.
140 REM AND ALSO SATURATION AS A FUNCTION OF LOCATION, AND SAT. AND MOISTURE
150 REM FILES THEN IT WILL ASK FOR THE SPECIMEN #, THE UPPER LIMIT ON LOCATION,
160 REM AND THE FULLY SATURATED PERMEABILITY VALUE. AFTER THE DATA IS INPUT,
170 REM THE COMPUTER WILL CALCULATE THE BODY FORCES B(L), AND B(0), DERIVATIVE
180 REM OF SATURATION S'(L), & S'(0), DERIVATIVE OF CAPILLARY PRESSURE C(S<L>),
190 REM C(S<0>) & THE INTEGRAL OF SATURATION TO CALCULATE THE REMOVED MOISTURE
200 REM AT THE END PROG. WILL CALCULATE THE UNSATURATED PERMEABILITY OF SAMPLE.
340 REM PUT THE DATA DISK FOR MOISTURE & SATURATION IN DRIVE # 1. THE DATA DISK
350 REM FOR S(Z), & PC(S) IN DRIVE #0.
400 DIM K3(18),K4(18),K5(18),TM(13),DM(13),P(40),S(40),UK(20),SS(20),NE(18)
405 DIM NS(18)
410 NE(1)=20:NE(2)=18:NE(3)=20:NE(4)=20:NS(1)=4:NS(2)=4:NS(3)=1:NS(4)=11
420 NE(5)=19:NE(6)=20:NE(7)=15:NE(8)=15:NS(5)=7:NS(6)=7:NS(7)=4:NS(8)=6:NS(9)=1
430 NE(9)=20:NE(10)=20:NE(11)=18:NE(12)=18:NS(10)=4:NS(11)=2:NS(12)=3:NS(13)=7
440 NE(13)=20:NE(14)=13:NE(15)=14:NE(16)=13:NS(14)=7:NS(15)=5:NS(16)=5:NS(17)=4
450 NE(17)=16:NE(18)=20:NS(18)=7
500 REM ASK FOR DATA TO BE PROVIDED BY THE USER.
510 INPUT"SPECIMEN # (11 TO 18)";SP:IFSP<=6THEN RN=9
511 IF (SP=7)AND(SP<=12) THEN RN=10
512 IFSP=13THEN RN=12
514 FOR E=1TO20:SS(E)=0:UK(E)=0:NEXT E
520 PRINT"UPPER LOCATION RANGE (L)";NS(SP);"TO";NE(SP);:INPUT L
530 INPUT"SATURATED PERMEABILITY (DARCYS)";PE:PE=PE*(9.87E-9)
540 REM READ IN DATA FOR PC(S), & S(Z).
550 SR=SP-13:IF SP>13 THEN 580
560 ONSFGOTO 9001,9002,9003,9004,9005,9006,9007,9008,9009,9010,9011,9012,9013
570 GO TO 590
580 ON SR GOTO 9014,9015,9016,9017,9018
590 REM START READING THE DATA FOR PC(S). REFERED TO
600 INPUT#3,D
610 INPUT#3,D
620 INPUT#3,D
630 INPUT#3,K0
640 INPUT#3,K1
650 INPUT#3,D
660 INPUT#3,D
670 INPUT#3,D
680 INPUT#3,D
690 INPUT#3,D
700 INPUT#3,D
710 INPUT#3,D
712 INPUT#3,D
714 INPUT#3,D
716 INPUT#3,D
720 CLOSE3:REM READ IN DATA FOR S(Z).
730 IF SP>13 THEN 770
750 ONSFGOTO 9101,9102,9103,9104,9105,9106,9107,9108,9109,9110,9111,9112,9113
760 GO TO 780
770 ON SR GOTO 9114,9115,9116,9117,9118.
780 REM READ IN DATA FOR S(Z). REFERED TO
790 INPUT#3,SP
800 INPUT#3,D
810 INPUT#3,D
820 FOR I=1 TO RN
830 INPUT#3,TM(I)
840 INPUT#3,DM(I)
850 INPUT#3,D

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860 INPUT#3,U
870 INPUT#3,D
880 INPUT#3,K3(I)
890 INPUT#3,K4(I)
900 INPUT#3,D
910 INPUT#3,D:INPUT#3,D:INPUT#3,D:INPUT#3,D
920 NEXT I:CLOSE#3:REM START THE MAIN CALCULATION.
922 IF SP=15 THEN TM(7)=9.8
1030 FOR I=1 TO RN-1
1050 IF SP<=6 THEN W=500
1060 IF SP>=7 AND SP<=12 AND I<=6 THEN W=845
1070 IF SP>=7 AND SP<=12 AND I>=7 THEN W=580
1080 IF SP>=13 AND SP<=18 AND I<=8 THEN W=200
1090 IF SP>=13 AND SP<=18 AND I>=9 THEN W=360
1130 REM PASS OVER THE RUNS IN WHICH THE W CHANGES.
1170 IF SP>=7 AND SP<=12 AND I=6 THEN TM(6)=0:W=580:REM CHANGE OF SPEED RUNS.
1180 IF SP>=13 AND SP<=18 AND I=8 THEN TM(8)=0:W=360:REM CHANGE OF SPEED RUNS.
1200 IF SP>13 THEN 1230
1210 ON SP GO TO 9200,9250,9300,9350,9400,9450,9500,9550,9600,9650,9700,9750,9800
1220 GO TO 1240
1230 ON SR GO TO 9850,9900,9950,10000,10050
1240 REM REFERED TO.
1256 IF SP=12 THEN S(8)=(S(7)+S(9))/2:S(28)=(S(27)+S(29))/2
1257 IF SP=13 THEN S(1)=S(2):S(21)=S(22)
1258 IF SP=14 AND I=1 THEN S(1)=.961
1259 IF SP=16 THEN S(13)=(S(12)+S(14))/2:S(33)=(S(32)+S(34))/2
1260 IF SP=16 AND I=1 THEN S(1)=.983
1261 IF SP=17 THEN S(12)=(S(11)+S(13))/2:S(32)=(S(31)+S(33))/2
1262 IF SP=17 AND I=1 THEN S(1)=.913
1263 IF SP=17 AND I=7 THEN S(21)=.913
1264 IF SP=17 AND I=8 THEN S(1)=.913
1265 IF SP=18 AND I=3 THEN S(21)=.968
1266 IF SP=18 AND I=4 THEN S(1)=.968
1269 REM CALCULATE THE BODY FORCES B(L), AND B(0).
1270 B0=((2*pi*W/60)*I2)*(24-P(NS(SP)))
1280 BL=((2*pi*W/60)*I2)*(24-P(L))
1300 REM CALCULATE THE S'(L), AND S'(0).
1310 SL=K3(I)*K4(I)*(P(L)+K4(I)-1.0)+(K3(I+1)*K4(I+1)*(P(L)+K4(I+1)-1.0))
1312 SL=SL/2
1315 S0=(K3(I)*K4(I)*(P(NS(SP))+K4(I)-1.0))
1317 S0=(S0+K3(I+1)*K4(I+1)*(P(NS(SP))+K4(I+1)-1.0))/2
1330 REM CALCULATE THE C(S(L)), AND C(S(0)).
1350 SS(I)=K3(I)*(P(L)+K4(I))+K3(I+1)*(P(L)+K4(I+1))
1360 SS(I)=SS(I)/2:CL=K0*K1*(SS(I)+K1-1.0)
1385 SX=(S(NS(SP))+S(NS(SP)+20))/2
1386 C0=K0*K1*(SX+K1-1.0)
1400 REM CALCULATE THE INTEGRAL PART.
1410 SN=0:SM=0
1420 FOR DD=NS(SP) TO L:SN=SN+S(DD):NEXT DD
1450 FOR DD=20+NS(SP) TO 20+L:SM=SM+S(DD):NEXT DD
1500 SZ=((SM-SN)*.4048)/((TM(I+1)-TM(I))*24*3600):REM TIME IN SECONDS.
1530 REM CALCULATE THE UNSATURATED PERMEABILITY.
1540 UK(I)=(PE*(C0*S0-B0)-(1.002E-2)*.63*SZ)/(CL*SL-BL)
2000 NEXT I
2030 REM PRINT OUT THE RESULTS.
2060 OPEN#4,CMD#4:PRINT#4,"UNSATURATED PERMEABILITY VALUES USING SPECIMEN #";SP
2070 PRINT#4,"UPPER LOCATION RANGE IS";L
2080 PRINT#4,"SATURATED PERMEABILITY VALUE IS";PE/(9.87E-9);"DARCYS"
2090 PRINT#4,"*****"
2095 PRINT#4,"SATURATION","PERMEABILITY (DARCYS)","K(S)/K(S(0))"
2100 FOR DD=1 TO RN-1
2102 IF SS(DD)=0 THEN 2130
2110 PRINT#4,SS(DD),
2120 PRINT#4,UK(DD)/(9.87E-9),
2125 PRINT#4,UK(DD)/PE
2130 NEXT DD

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2140 PRINT#4,"*****"
2150 PRINT#4:CLOSE4
2180 REM REDO THE CALCULATION WITH NEW PARAMETERS.
2190 PRINT"DO YOU WANT ANOTHER RUN WITH DIFFERENT PARAMETERS Y/N":INPUT A#
2200 IF A#="Y" THEN 500
5000 END
9001 OPEN3,8,9,"0:01PCOFSAT QUAD,SEQ,READ":GO TO 590
9002 OPEN3,8,9,"0:02PCOFSAT QUAD,SEQ,READ":GO TO 590
9003 OPEN3,8,9,"0:03PCOFSAT QUAD,SEQ,READ":GO TO 590
9004 OPEN3,8,9,"0:04PCOFSAT QUAD,SEQ,READ":GO TO 590
9005 OPEN3,8,9,"0:05PCOFSAT QUAD,SEQ,READ":GO TO 590
9006 OPEN3,8,9,"0:06PCOFSAT QUAD,SEQ,READ":GO TO 590
9007 OPEN3,8,9,"0:07PCOFSAT QUAD,SEQ,READ":GO TO 590
9008 OPEN3,8,9,"0:08PCOFSAT QUAD,SEQ,READ":GO TO 590
9009 OPEN3,8,9,"0:09PCOFSAT QUAD,SEQ,READ":GO TO 590
9010 OPEN3,8,9,"0:10PCOFSAT QUAD,SEQ,READ":GO TO 590
9011 OPEN3,8,9,"0:11PCOFSAT QUAD,SEQ,READ":GO TO 590
9012 OPEN3,8,9,"0:12PCOFSAT QUAD,SEQ,READ":GO TO 590
9013 OPEN3,8,9,"0:13PCOFSAT QUAD,SEQ,READ":GO TO 590
9014 OPEN3,8,9,"0:14PCOFSAT QUAD,SEQ,READ":GO TO 590
9015 OPEN3,8,9,"0:15PCOFSAT QUAD,SEQ,READ":GO TO 590
9016 OPEN3,8,9,"0:16PCOFSAT QUAD,SEQ,READ":GO TO 590
9017 OPEN3,8,9,"0:17PCOFSAT QUAD,SEQ,READ":GO TO 590
9018 OPEN3,8,9,"0:18PCOFSAT QUAD,SEQ,READ":GO TO 590
9101 OPEN3,8,9,"0:01SOFLC,SEQ,READ":GO TO 780
9102 OPEN3,8,9,"0:02SOFLC,SEQ,READ":GO TO 780
9103 OPEN3,8,9,"0:03SOFLC,SEQ,READ":GO TO 780
9104 OPEN3,8,9,"0:04SOFLC,SEQ,READ":GO TO 780
9105 OPEN3,8,9,"0:05SOFLC,SEQ,READ":GO TO 780
9106 OPEN3,8,9,"0:06SOFLC,SEQ,READ":GO TO 780
9107 OPEN3,8,9,"0:07SOFLC,SEQ,READ":GO TO 780
9108 OPEN3,8,9,"0:08SOFLC,SEQ,READ":GO TO 780
9109 OPEN3,8,9,"0:09SOFLC,SEQ,READ":GO TO 780
9110 OPEN3,8,9,"0:10SOFLC,SEQ,READ":GO TO 780
9111 OPEN3,8,9,"0:11SOFLC,SEQ,READ":GO TO 780
9112 OPEN3,8,9,"0:12SOFLC,SEQ,READ":GO TO 780
9113 OPEN3,8,9,"0:13SOFLC,SEQ,READ":GO TO 780
9114 OPEN3,8,9,"0:14SOFLC,SEQ,READ":GO TO 780
9115 OPEN3,8,9,"0:15SOFLC,SEQ,READ":GO TO 780
9116 OPEN3,8,9,"0:16SOFLC,SEQ,READ":GO TO 780
9117 OPEN3,8,9,"0:17SOFLC,SEQ,READ":GO TO 780
9118 OPEN3,8,9,"0:18SOFLC,SEQ,READ":GO TO 780
9700 REM SPECIMEN #11 SATURATION AND MOISTURE CONTENT DATA INPUT.
9701 ONIGOSUB9703,9707,9711,9715,9719,9723,9727,9731,9735
9702 GO TO 1240
9703 OPEN3,8,9,"1:11MS00,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9704 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTD:CLOSE3
9705 OPEN3,8,9,"1:11MS01,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9706 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9707 OPEN3,8,9,"1:11MS01,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9708 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTD:CLOSE3
9709 OPEN3,8,9,"1:11MS02,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9710 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9711 OPEN3,8,9,"1:11MS02,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9712 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTD:CLOSE3
9713 OPEN3,8,9,"1:11MS03,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9714 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9715 OPEN3,8,9,"1:11MS03,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9716 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTD:CLOSE3
9717 OPEN3,8,9,"1:11MS04,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9718 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9719 OPEN3,8,9,"1:11MS04,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9720 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTD:CLOSE3
9721 OPEN3,8,9,"1:11MS05,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9722 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9723 OPEN3,8,9,"1:11MS05,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D

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9724 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9725 OPEN3,8,9,"1:11MS06,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9726 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9727 OPEN3,8,9,"1:11MS06,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9728 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9729 OPEN3,8,9,"1:11MS07,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9730 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9731 OPEN3,8,9,"1:11MS07,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9732 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9733 OPEN3,8,9,"1:11MS08,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9734 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9735 OPEN3,8,9,"1:11MS08,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9736 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9737 OPEN3,8,9,"1:11MS09,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9738 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9750 REM SPECIMEN #12 SATURATION AND MOISTURE CONTENT DATA INPUT.
9751 ONIGOSUB9753,9757,9761,9765,9769,9773,9777,9781,9785
9752 GO TO 1240
9753 OPEN3,8,9,"1:12MS00,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9754 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9755 OPEN3,8,9,"1:12MS01,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9756 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9757 OPEN3,8,9,"1:12MS01,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9758 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9759 OPEN3,8,9,"1:12MS02,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9760 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9761 OPEN3,8,9,"1:12MS02,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9762 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9763 OPEN3,8,9,"1:12MS03,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9764 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9765 OPEN3,8,9,"1:12MS03,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9766 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9767 OPEN3,8,9,"1:12MS04,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9768 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9769 OPEN3,8,9,"1:12MS04,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9770 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9771 OPEN3,8,9,"1:12MS05,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9772 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9773 OPEN3,8,9,"1:12MS05,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9774 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9775 OPEN3,8,9,"1:12MS06,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9776 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9777 OPEN3,8,9,"1:12MS06,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9778 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9779 OPEN3,8,9,"1:12MS07,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9780 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9781 OPEN3,8,9,"1:12MS07,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9782 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9783 OPEN3,8,9,"1:12MS08,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9784 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9785 OPEN3,8,9,"1:12MS08,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9786 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9787 OPEN3,8,9,"1:12MS09,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9788 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9800 REM SPECIMEN #13 SATURATION AND MOISTURE CONTENT DATA INPUT.
9801 ONIGOSUB9803,9807,9811,9815,9819,9823,9827,9831,9835,9839,9843
9802 GO TO 1240
9803 OPEN3,8,9,"1:13MS00,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9804 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9805 OPEN3,8,9,"1:13MS01,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9806 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9807 OPEN3,8,9,"1:13MS01,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9808 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9809 OPEN3,8,9,"1:13MS02,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9810 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9811 OPEN3,8,9,"1:13MS02,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D

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9812 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9813 OPEN3,8,9,"1:13MS03,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9814 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9815 OPEN3,8,9,"1:13MS03,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9816 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9817 OPEN3,8,9,"1:13MS04,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9818 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9819 OPEN3,8,9,"1:13MS04,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9820 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9821 OPEN3,8,9,"1:13MS05,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9822 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9823 OPEN3,8,9,"1:13MS05,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9824 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9825 OPEN3,8,9,"1:13MS06,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9826 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9827 OPEN3,8,9,"1:13MS06,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9828 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9829 OPEN3,8,9,"1:13MS07,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9830 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9831 OPEN3,8,9,"1:13MS07,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9832 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9833 OPEN3,8,9,"1:13MS08,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9834 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9835 OPEN3,8,9,"1:13MS08,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9836 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9837 OPEN3,8,9,"1:13MS09,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9838 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9839 OPEN3,8,9,"1:13MS09,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9840 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9841 OPEN3,8,9,"1:13MS10,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9842 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9843 OPEN3,8,9,"1:13MS10,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9844 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9845 OPEN3,8,9,"1:13MS11,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9846 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9850 REM SPECIMEN #14 SATURATION AND MOISTURE CONTENT DATA INPUT.
9851 ONIGOSUB9853,9857,9861,9865,9869,9873,9877,9881,9885,9889,9893
9852 GO TO 1240
9853 OPEN3,8,9,"1:14MS00,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9854 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9855 OPEN3,8,9,"1:14MS01,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9856 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9857 OPEN3,8,9,"1:14MS01,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9858 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9859 OPEN3,8,9,"1:14MS02,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9860 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9861 OPEN3,8,9,"1:14MS02,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9862 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9863 OPEN3,8,9,"1:14MS03,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9864 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9865 OPEN3,8,9,"1:14MS03,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9866 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9867 OPEN3,8,9,"1:14MS04,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9868 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9869 OPEN3,8,9,"1:14MS04,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9870 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9871 OPEN3,8,9,"1:14MS05,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9872 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9873 OPEN3,8,9,"1:14MS05,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9874 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9875 OPEN3,8,9,"1:14MS06,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9876 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9877 OPEN3,8,9,"1:14MS06,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9878 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9879 OPEN3,8,9,"1:14MS07,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9880 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN

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9881 OPEN3,8,9,"1:14MS07,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9882 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9883 OPEN3,8,9,"1:14MS08,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9884 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9885 OPEN3,8,9,"1:14MS08,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9886 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9887 OPEN3,8,9,"1:14MS09,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9888 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9889 OPEN3,8,9,"1:14MS09,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9890 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9891 OPEN3,8,9,"1:14MS10,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9892 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9893 OPEN3,8,9,"1:14MS10,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9894 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9895 OPEN3,8,9,"1:14MS11,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9896 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9900 REM SPECIMEN #15 SATURATION AND MOISTURE CONTENT DATA INPUT.
9901 ONIGOSUB9903,9907,9911,9915,9919,9923,9927,9931,9935,9939,9943
9902 GO TO 1240
9903 OPEN3,8,9,"1:15MS00,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9904 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9905 OPEN3,8,9,"1:15MS01,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9906 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9907 OPEN3,8,9,"1:15MS01,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9908 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9909 OPEN3,8,9,"1:15MS02,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9910 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9911 OPEN3,8,9,"1:15MS02,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9912 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9913 OPEN3,8,9,"1:15MS03,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9914 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9915 OPEN3,8,9,"1:15MS03,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9916 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9917 OPEN3,8,9,"1:15MS04,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9918 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9919 OPEN3,8,9,"1:15MS04,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9920 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9921 OPEN3,8,9,"1:15MS05,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9922 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9923 OPEN3,8,9,"1:15MS05,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9924 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9925 OPEN3,8,9,"1:15MS06,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9926 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9927 OPEN3,8,9,"1:15MS06,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9928 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9929 OPEN3,8,9,"1:15MS07,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9930 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9931 OPEN3,8,9,"1:15MS07,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9932 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9933 OPEN3,8,9,"1:15MS08,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9934 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9935 OPEN3,8,9,"1:15MS08,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9936 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9937 OPEN3,8,9,"1:15MS09,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9938 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9939 OPEN3,8,9,"1:15MS09,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9940 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9941 OPEN3,8,9,"1:15MS10,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9942 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9943 OPEN3,8,9,"1:15MS10,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9944 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9945 OPEN3,8,9,"1:15MS11,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9946 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9950 REM SPECIMEN #16 SATURATION AND MOISTURE CONTENT DATA INPUT.
9951 ONIGOSUB9953,9957,9961,9965,9969,9973,9977,9981,9985,9989,9993
9952 GO TO 1240

```

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9953 OPEN3,8,9,"1:16MS00,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9954 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9955 OPEN3,8,9,"1:16MS01,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9956 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9957 OPEN3,8,9,"1:16MS01,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9958 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9959 OPEN3,8,9,"1:16MS02,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9960 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9961 OPEN3,8,9,"1:16MS02,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9962 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9963 OPEN3,8,9,"1:16MS03,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9964 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9965 OPEN3,8,9,"1:16MS03,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9966 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9967 OPEN3,8,9,"1:16MS04,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9968 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9969 OPEN3,8,9,"1:16MS04,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9970 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9971 OPEN3,8,9,"1:16MS05,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9972 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9973 OPEN3,8,9,"1:16MS05,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9974 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9975 OPEN3,8,9,"1:16MS06,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9976 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9977 OPEN3,8,9,"1:16MS06,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9978 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9979 OPEN3,8,9,"1:16MS07,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9980 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9981 OPEN3,8,9,"1:16MS07,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9982 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9983 OPEN3,8,9,"1:16MS08,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9984 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9985 OPEN3,8,9,"1:16MS08,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9986 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9987 OPEN3,8,9,"1:16MS09,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9988 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9989 OPEN3,8,9,"1:16MS09,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9990 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9991 OPEN3,8,9,"1:16MS10,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9992 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
9993 OPEN3,8,9,"1:16MS10,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9994 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
9995 OPEN3,8,9,"1:16MS11,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
9996 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
10000 REM SPECIMEN #17 SATURATION AND MOISTURE CONTENT DATA INPUT.
10001 ONIGOSUB10003,10007,10011,10015,10019,10023,10027,10031,10035,10039,10043
10002 GO TO 1240
10003 OPEN3,8,9,"1:17MS00,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
10004 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
10005 OPEN3,8,9,"1:17MS01,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
10006 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
10007 OPEN3,8,9,"1:17MS01,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
10008 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
10009 OPEN3,8,9,"1:17MS02,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
10010 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
10011 OPEN3,8,9,"1:17MS02,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
10012 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
10013 OPEN3,8,9,"1:17MS03,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
10014 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
10015 OPEN3,8,9,"1:17MS03,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
10016 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
10017 OPEN3,8,9,"1:17MS04,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
10018 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
10019 OPEN3,8,9,"1:17MS04,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
10020 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
10021 OPEN3,8,9,"1:17MS05,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D

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10022 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
10023 OPEN3,8,9,"1:17MS05,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
10024 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
10025 OPEN3,8,9,"1:17MS06,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
10026 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
10027 OPEN3,8,9,"1:17MS06,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
10028 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
10029 OPEN3,8,9,"1:17MS07,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
10030 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
10031 OPEN3,8,9,"1:17MS07,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
10032 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
10033 OPEN3,8,9,"1:17MS08,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
10034 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
10035 OPEN3,8,9,"1:17MS08,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
10036 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
10037 OPEN3,8,9,"1:17MS09,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
10038 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
10039 OPEN3,8,9,"1:17MS09,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
10040 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
10041 OPEN3,8,9,"1:17MS10,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
10042 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
10043 OPEN3,8,9,"1:17MS10,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
10044 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
10045 OPEN3,8,9,"1:17MS11,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
10046 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
10050 REM SPECIMEN #18 SATURATION AND MOISTURE CONTENT DATA INPUT.
10051 ONIGOSUB10053,10057,10061,10065,10069,10073,10077,10081,10085,10089,10093
10052 GO TO 1240
10053 OPEN3,8,9,"1:18MS00,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
10054 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
10055 OPEN3,8,9,"1:18MS01,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
10056 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
10057 OPEN3,8,9,"1:18MS01,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
10058 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
10059 OPEN3,8,9,"1:18MS02,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
10060 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
10061 OPEN3,8,9,"1:18MS02,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
10062 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
10063 OPEN3,8,9,"1:18MS03,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
10064 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
10065 OPEN3,8,9,"1:18MS03,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
10066 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
10067 OPEN3,8,9,"1:18MS04,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
10068 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
10069 OPEN3,8,9,"1:18MS04,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
10070 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
10071 OPEN3,8,9,"1:18MS05,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
10072 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
10073 OPEN3,8,9,"1:18MS05,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
10074 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
10075 OPEN3,8,9,"1:18MS06,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
10076 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
10077 OPEN3,8,9,"1:18MS06,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
10078 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
10079 OPEN3,8,9,"1:18MS07,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
10080 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
10081 OPEN3,8,9,"1:18MS07,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
10082 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
10083 OPEN3,8,9,"1:18MS08,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
10084 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
10085 OPEN3,8,9,"1:18MS08,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
10086 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
10087 OPEN3,8,9,"1:18MS09,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
10088 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
10089 OPEN3,8,9,"1:18MS09,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
10090 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3

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```

10091 OPENS,8,9,"1:18MS10,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
10092 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
10093 OPENS,8,9,"1:18MS10,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
10094 FORDD=1T020:INPUT#3,P<DD>,D,S<DD>:NEXTDD:CLOSE3
10095 OPENS,8,9,"1:18MS11,SEQ,READ":INPUT#3,D:INPUT#3,D:INPUT#3,D
10096 FORDD=21T040:INPUT#3,P<DD>,D,S<DD>:NEXT:CLOSE3:RETURN
READY.

READY.

```

READY.

```

10 REM THIS PROGRAM CALCULATES THE CURVE FIT VALUES FOR POWER, & QUADRATIC EQ.
20 REM FOR PERMEABILITY AS A FUNCTION OF SATURATION.
30 REM
40 REM JANUARY 1984, FARID PIROOZMANDI.
50 REM
60 DIM S(100),K(100)
70 REM
80 REM INPUT DATA FROM DRIVE #1.
90 REM
100 OPEN#3,9,"1:K(S)3,SEQ,READ"
110 INPUT#3,H
120 FOR I=1 TO N
130 INPUT#3,S(I),K(I)
140 NEXT I
150 CLOSE#3
155 PRINT#3:FOR I=1 TO N:PRINTS(I);K(I):NEXT I
160 REM
170 REM START CALCULATION FOR QUADRATIC EQUATION.
180 REM
185 L1=0:L2=0:L3=0:L4=0:L5=0:L6=0:L7=0:L8=0
190 FOR I=1 TO N
200 L1=L1+S(I)
210 L2=L2+(S(I)^2)
220 L3=L3+K(I)
230 L4=L4+(S(I)^3)
240 L5=L5+(S(I)*K(I))
250 L6=L6+(S(I)^4)
260 L7=L7+(K(I)*(S(I)^2))
270 L8=L8+(K(I)^2)
280 NEXT I
290 REM
300 NU=L2*L3*(L6^2)-L3*L6*(L4^2)-L5*(L6^2)*L1+L4*L7*L6*L1-(L2^2)*L7*L6
310 NU=NU+L2*L4*L5*L6
320 REM
330 DE=H*L2*(L6^2)-H*L6*(L4^2)-(L1^2)*(L6^2)+2*L2*L4*L1*L6-(L2^3)*L6
340 REM
350 K0=NU/DE
360 REM
370 NU=L5*L6-L4*L7-K0*(L1*L6-L4*L2)
380 DE=L2*L6-(L4^2)
390 REM
400 K1=NU/DE
410 REM
420 NU=L7-K0*L2-K1*L4
430 K2=NU/L6
440 REM CALCULATE CORRELATION COEFFICIENT.
445 L9=0:LA=0
450 FOR I=1 TO N
455 CR=(K0+K1*S(I)+K2*(S(I)^2)
460 L9=L9+(K(I)-CR)^2
465 PRINTK(I);CR
470 LA=LA+(K(I)-(L3/N))^2
480 NEXT I
490 REM
500 R2=(ABS(1-L9/LA))^1.5:REM CORRELATION COEFFICIENT.
510 REM
520 REM
530 REM START CALCULATION OF THE POWER EQUATION.
540 REM
550 LB=0:LC=0:LD=0:LE=0:LF=0:LG=0:LH=0

```

```

560 REM TAKE THE LOG. OF THE DATA POINTS.
570 FOR I=1 TO N
580 S(I)=LOG(S(I))
590 K(I)=LOG(K(I))
600 NEXT I
610 REM
620 FOR I=1 TO N
630 LB=LB+S(I)*K(I)
640 LC=LC+(S(I)^2)
645 LF=LF+(K(I)^2)
650 LD=LD+S(I)
660 LE=LE+K(I)
670 NEXT I
680 REM
690 NU=N*LB-LD*LE
700 DE=N*LC-(LD^2)
710 DL=NU/DE
720 CL=EXP((1/N)*LE-(DL/N)*LD)
730 REM POWER EQ. K=CL*S^DL
740 REM CORRELATION COEFFICIENT.
750 NU=N*LB-LD*LE
760 DE=((N*LC-(LD^2))^1.5)*((N*LF-(LE^2))^1.5)
770 RP=NU/DE:REM CORRELATION COEFFICIENT.
780 REM
790 REM
800 REM PRINT OUT THE RESULTS.
810 OPEN#4,"CHD4
820 PRINT#4,"QUADRATIC EQUATION K=K0+K1*S+K2*S^2"
830 PRINT#4,"K0=";K0;"K1=";K1;"K2=";K2
840 PRINT#4,"CORRELATION COEFFICIENT IS ";R2
850 PRINT#4,"POWER EQUATION K=C*S^D "
860 PRINT#4,"C=";CL;"D=";DL
870 PRINT#4,"CORRELATION COEFFICIENT IS ";RP
880 CLOSE#4
890 END
READY.

READY.

READY.

```