Available online at www.elixirpublishers.com (Elixir International Journal)

Mechanical Engineering

Elixir Mech. Engg. 107 (2017) 47000-47005

ISSN: 2229-712X

Design and Construction of Pressure Membrane Apparatus for Measurement of Soil Moisture Tension of Soils under Laboratory Condition.

[1]Uzoigwe, L.O, [2]Udeorji, C.K and [3]Nwofor E.C

[1,2&3]Department of Agricultural Engineering, Imo State University Owerri,Nigeria.

ARTICLE INFO

Article history:

Received: 10 April 2017;
Received in revised form: 11 May 2017;
Accepted: 6 June 2017;

Keywords

Pressure membrane apparatus,
Soil moisture potential sealed pressure cell,
Capillary force.

ABSTRACT

Environmental factors such as climate change, gradual decrease in water resources and threatened habitants prompted the need to monitor our environment and implement better policies to protect it, thus monitoring soil pF (potential factor) values become increasingly important for environmental monitoring. The commonly available Instrument (tensiometer) do not measure the range of available moisture in all soil types rather measures soil water suction. The need to measure the range of available moisture in all soil types with accuracy led to the modification of tensiometer for satisfactory laboratory results. Due to the shortcomings associated with tensiometer readings, the pressure membrane apparatus is an important instrument for optimizing irrigation and erosion prediction models. This pressure membrane with extractor has two main components: a porous plate with air entry pressure and a sealed pressure cell. The soil from which pF value was to be determined was placed in a chamber in which the pressure increased above atmospheric pressure. The side of the chamber which supports the soil consists of a pressure relief valve supported on a pressure hose. This is to ensure that the extractor chamber was not over-pressurized. The soil water potential with the corresponding moisture contents of four soil samples: A (clay soil), B (loamy soil), C (sandy soil) and D (silt) obtained from different locations were determined using pressure membrane apparatus. At a potential of 104hPa, samples A, B, C, and D showed moisture content of 0.05, 0.25, 0.30, and 0.45cm ^{3}/cm^3 respectively. From the obtained results, at potential close to zero, sandy soil is close to saturation and moisture held in the soil, primarily by capillary forces. From the laboratory analysis, moisture content decreases with high moisture cohesion.

1.0 Introduction

Over the past fifteen years, environment monitoring has become increasingly important. Environmental factors such as climate change, gradual decrease in water resources, and threatened habitants are driving the need to monitor the environment and implement better policies to protect it. (Agbakwuru et al., 2011). Monitoring soil potential factor (pF) conditions provide necessary facts for the protection and maintenance of local and regional water resources.

Irrigation of crops represents about 90% of water used throughout the world. To maximize profits, irrigation water must be applied on a schedule for its efficient use. Monitoring soil potential factor (pF) in the root zone of crops will optimize irrigation. Optimizing irrigation scheduling will increase crop yields, protect local water resources from runoff, save water energy and fertilizer costs thereby increasing farm profitability. Thus, soil pF monitoring is used to characterize the hydrological requirements of biomass. Erosion that results from changes in land use causes serious damages to properties and natural water systems. To understand the causes of erosion and make predictions about when and where erosion occurs, rainfall, sediment and soil moisture to be recorded.

Monitoring soil pF is thus, an important input parameter into erosion prediction models, (Arora, 2014).

In recent years, climate change modelers and environmental programmers have identified soil as a major source and a major sink for green house gases. (Toppet al., 1980; Gardener, 1986; Agbakwuru, 2011; White and Zegelin, 2015). As the fields are titled in preparation for planting, organic soils become more available to micro organisms. Each year, tons of green house gases are released into the atmosphere from agricultural tillage. Cultivating crops reduce the emission of green house gases from the soil. Increase in the organic component in the soil increases the soils water holding capacity, (Allison et al., 1983; Heimovaaraet al., 1990; Johnson and Borough, 1992; Kachanoskiet al., 1992; Bell et al., 2012). Thus, to measure and record the soil moisture content of the soil, soil pF determining instrument is needed. Data from pressure membrane apparatus are thus, used to characterize the effectiveness of number of tillage method and estimate the rate of green house production in specific soils, (Michael, 2014).

To optimize irrigation schedule, Michael and Ojha (2013), Larry (2014), and Robert et al.(2014), characterized the hydrological requirements of biomass crops, understand the causes of erosion, characterize the effective number of

Tele: 07038033178
E-mail address: chidiebereudeorji@gmail.com

tillage method and estimate the rate of green house gas production in specific soil, there is utmost need to measure and determine the soil pF values. The dynamic measurement of soil water content requires a sensitive pF measurement adopted in the pressure membrane apparatus designed and constructed as proposed by Gardener (1986), Whally et al. (1992) and Kramer et al. (1992), for the determination of pF of different soils. Different methods and devices for determining soil pF in the field are already in existence. However, monitoring soil pF in the laboratory calls for an accurate method that allows repeated measurements through time.

2.0 Materials and Methods

2.1 Materials

Sourcing materials for the implementation of this work were of great importance. They were purchased from our local markets, which successfully improved onthe construction of the pressure extractor chamber, air filter, water trap, bolts and nuts, pressure hose, capacitor, pressure gauge, safety relief valve, compressor, corks, worm screw, plate, mild steel plate, iron pipe, ball valves and outflow tube.

2.2 Methods

In order to choose the appropriate and cheapest method to adopt in this work, two things were considered.

The processes that would be involved and the necessary technology required.

The availability of materials/components required for implementation.

The bottom-top approach method was used to realize the work. In this method, each section of the work was developed and tested forend coupling.

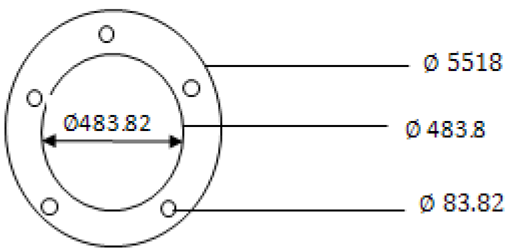
Procedure employed in casting and machining of the extraction chamber to meet the design specification includes: bolt dimension =14mmØ, (ii) Cylinder wall thickness t= 1.5mm (iii) Cylinder head of sizes; D_1 = 16mm, D_0= 186.82mm, D_p = 93.41mm, (iv) Cylinder head thickness t1=12.8mm for the lower chamber, Cylinder flange thickness t2 = 28mm and machining the base plate for operational freedom.

2.3 Technical specification

Components used in the design were thoroughly selected in order to meet the design goals, thus leading to the following design considerations.

2.3.1 Core bolt design

In determining the size and number of bolts, Figure 2.1 was adopted.



All Dimensions in mm

Figure 2.1: Design of core bolt.

The initial tension for the bolt design was found by the relation.

$$P_i = 2840D\ (N) \quad (2.1)$$

where,

P_i=Initial tension in bolt

D =Normal diameter of bolt in (mm)

Resultant axial load

$$P = P_i\,(a/1 + a) \times P_2 = KP_2 \quad (2.2)$$

where,

P_i= initial tension due to tightening of the bolt.

P_2= external load on the bolt, and

K= correction factor (0.5-0.75)

$$F = \frac{P \times A}{4} \quad (2.3)$$

where,

F = force exerted on the bolt

A = area

$$F = \frac{10 \times 10^5 \times \pi d^2}{4} = \frac{10 \times 10^5 \times \pi (0.08382)^2}{4} = 5518.04N$$

Therefore, each bolt will carry 5518.04N

$$P_2 = 191.67N$$

From experiment

$$P_i = P_1(p_i \times KP_2)N \quad (2.4)$$

$$P_i = P_1\{2840D + 0.5\,(191.67)\}N$$

For mild steel

$$P_i = \sigma \times A = 56 \times 10^6 A. \quad (2.5)$$

That is force resulting from stress in bolt member

Also,

$$Dc = 0.84D$$

where,

Dc = core diameter of bolt

D = Cylinder diameter

$$P_1 = 56 \times 10^6 \times \frac{(0.84d \times 10^{-3})^2}{4}\pi$$

From Equation (2.4),

$$2840D + 459.84 = 31.03D^2$$

$$31.03D^2 - 2840D = 459.84$$

Solving simultaneously and dividing through by 31.03

$$D^2 - 91.52 = 14.82$$

$$D^2 - 91.52 + (45.76)^2 = 14.82 + 2093.98 = 2108.798$$

$$(D - 45.76)^2 = \pm\,(2108.798) = \pm\,45.92$$

$$D = 45.92 + 45.76 \text{ or } - 45.92 - 45.767$$

$$D = 91.68mm$$

$$Dc = 0.84D = 0.84 \times 91.68 = 77.01mm$$

The value obtained using this value for initial preload is high, so assuming that the forces were uniformly distributed on the two bolts. Then:

$$5518.02N \times 2 = 11036.68N$$

$$(\pi Dc^2\sigma)/4 = (\pi Dc^2 \times 56 \times 10^6)/4$$

$$Dc^2 = 2.5 \times 10^{-4}$$

$$Dc = \sqrt{2.5 \times 10^{-4}} = 0.0158m \text{ or } 15.8mm$$

This corresponds to M-14 bolt series or M-16 bolt series. (15:4218 part III 1976 edited 1996).

2.2.2 Design of cylinder components

a. Cylinder wall thickness design

If the wall thickness of a cylinder pressure vessel is about one twentieth of its radius, the thickness of the cylinder wall is considered as a thin wall pressure vessel. That is

$$t < {}^{1}/_{2} \quad (2.6)$$

Hence, the thickness of the cylinder wall is considered as a thin wall pressure vessel, and calculated from

$$t = \frac{p \times d + c}{2\sigma t_1} \quad (2.7)$$

Where,

p = Intensity of internal pressure
d = Internal diameter of the cylinder shell
t =Thickness of the cylinder shell
σt_1= circumferential or hoop stress for the material of the cylinder shell

$$c = \text{the allowance for re} - \text{boring}$$

Considering a ductile material, the value of circumferential stress (σt_i) may be taken as 0.8 times the yield point stress (dy) i.e. σt_i= 0.8dy

Where dy = 34.55 mPa for pure aluminum

$$\sigma t_i = 0.8 \text{ x } 34.55 = 27.64\text{mPa}$$

As a factor of safety in the design of this cylinder, the maximum internal pressure would be used as 10bar

$$t = \frac{10 \times 10^5 \times 83.8242}{2 \times 27.64 \times 10^6} = 1.5mm$$

b. Cylinder base size for lower chamber design

$$D_o = D_p + D_p \quad (2.8)$$

$$D_p = 3D_1 + 2t + D + 3D_1 \quad (2.9)$$

$$D_0 = 6D_1 + 2t + D_p \quad (2.10)$$

Where,

D_0 = *Overall diameter* = 186.82mm
D_p = *Pitch cycle diameter* =93.41mm
t = *Cylinder thickness* = 1.5mm

Since the bolt required on the cylinder head is M14 (10mm nominal diameter).

$$D_0 = 6(16) + 2(3.5) + 83.82$$

$$96 + 7 + 83.82 = 186.82mm$$

D_o= 186.82mm

For pitch circle diameter

$$D_p = 3d1 + 2t + d = 3(16) + 2(3.5) + 83.82$$

$$D_p = 48 + 7 + 83 - 82$$

$$D_p = 93.41mm$$

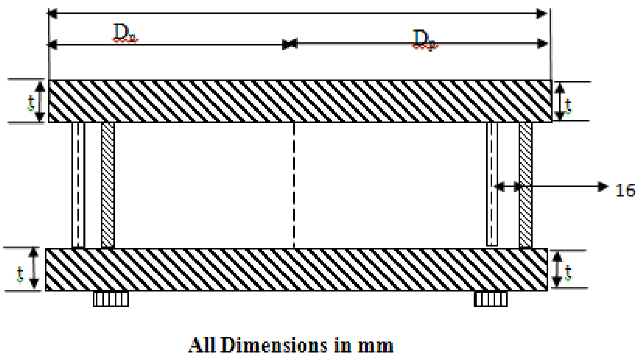


Figure 2.2: Cylinder base size lower chamber.

D_o= 186.82, D_p= 93.41, t = 1.5

The centres of the bolts are to be placed on this line, Figure 2.2.

c. Cylinder head thickness for the upper chamber design

The cylinder head thickness for the upper chamber Figure 2.3 has internal pressure present in the cylinder due to pressure supplied (air) tries to leave cylinder cover while the bolt tries to retain it in its position. But the pressures of these two loads do not coincide. Hence the cover plate is subjected to bending stress. The sectional modulus is shown in Figure 2.4

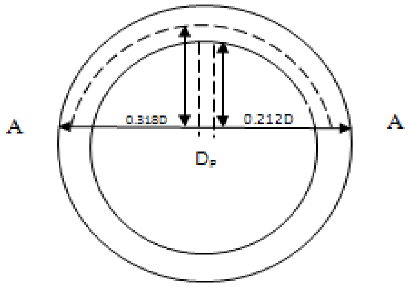


Figure 2.3: Cylinder head thickness for the upper chamber

$$M = \frac{total\ bolt\ load(0\ x - 0y)}{2} \quad (2.11)$$

$$\frac{p/2\ (0.318D_p - 0.212D_p)}{2} = p/2 \times 0.106D_p$$

$$= 0.53D_p$$

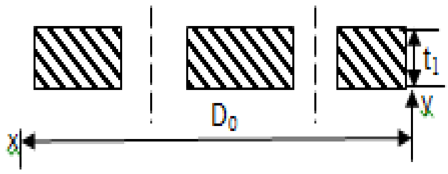


Figure 2.4: Sectional modulus.

t_1= 1.5, D_0 = 186.82

All Dimensions in mm

$$W = Width\ of\ plate\text{–}\ outside\ diameter\ of\ cover\ plate \times diameter\ of\ hole\ width\ of\ plate$$

$$W = D_o - 2D_1 = 186.82 - 2(16) = 154.82mm$$

But

$$z = ½ \times W \times (t_1)^2 and\ \partial t = m/2$$

$$z = m/\partial t$$

$$z = 1/6\ wt_1{}^2 = m/\partial_t$$

$$t_1{}^2 = \frac{6m}{w\partial t} = \frac{6 \times 0.053D_P}{w\partial t}$$

$$t_1{}^2 = 0.318D_P/\ w\partial t$$

$$P = Total\ bolt\ load = 6 \times 5518.04$$

$$P = 33108.24N$$

$$\partial_t = 56MP_a$$

$$t_1{}^2 = 164.33 \times 10^6$$

$$t_1 = \sqrt{1.64 \times 10^4} = 0.0128m\ or\ 12.8mm$$

If the thickness t_1= 12.8mm and allowance are made on this head for suction and discharge values, definitely it will affect the strength of the load due to removal of material. In order to correct this, the thickness was increased to 15mm.

D. Cylinder flange thickness design

The thickness of the flange (t_2) may be determined from bending consideration. A portion of the cylinder flange under the influence of one bolt is shown in Figure 2.5.

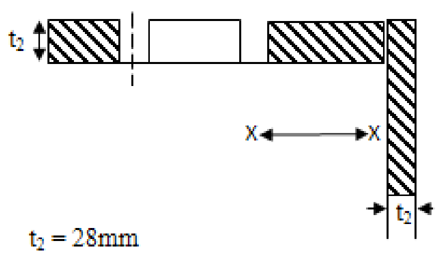


Figure 2.5: Cylinder flange under influence.

The load in the bolt produces bending stress in the section x – x. The geometry of the figure eccentricity of the load from the section x – x is

$$\boldsymbol{E = pitch\ circle}$$
$$\boldsymbol{= (bore\ radius + thickness\ of\ cylinder\ wall)}$$
$$\boldsymbol{Bending\ moment = load\ one\ ach\ bolt \times E}$$
$$\boldsymbol{= 5518.04 \times (57.91 \times 10^2)}$$
$$\boldsymbol{= 3195.5Nm}$$

Radius of the section x – x

$$\boldsymbol{R = cylinder\ radius + thickness\ of\ cylinder\ wall}$$
$$\boldsymbol{R = \frac{D_p}{2} + t = \frac{83.82}{2} + 3.5 = 45.41mm}$$

With number bolt

$$\boldsymbol{W = (2\pi \times 45.41)/6 = 47.53mm}$$

Section modulus

$$\boldsymbol{Z = 1/6\, w(t_2)^2}$$
$$\boldsymbol{Z = 1/6 \times 47.53 \times 10^{-3} t_2{}^2}$$

Recall that z = M/∂t

$$\boldsymbol{Z = 319.55/50 \times 10^6}$$
$$\boldsymbol{\frac{319.55}{50} \times 10^6 = 1/6 \times 47.53 \times 10^{-3} t_2{}^2}$$
$$\boldsymbol{t_2 = \sqrt{0.8068 \times 10^{-3}} = 28mm}$$

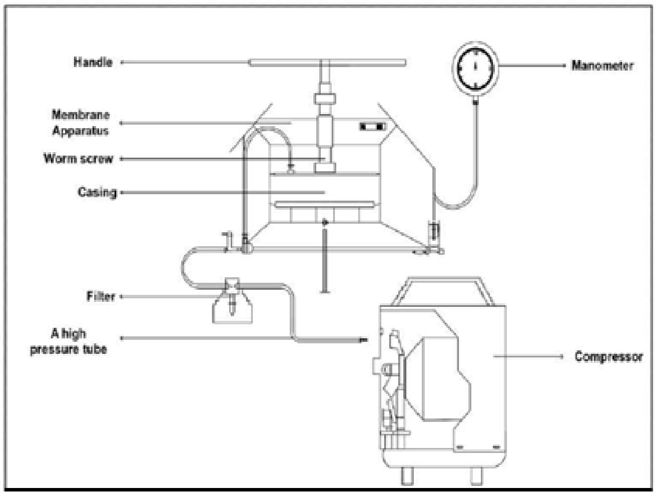


Figure 2.6: Pressure membrane apparatus.

1 2 3

Plate 1: Membrane apparatus with rings.
Plate 2: Membrane apparatus with the relief valve and manometer gauge.
Plate 3: Handle and worm screw.

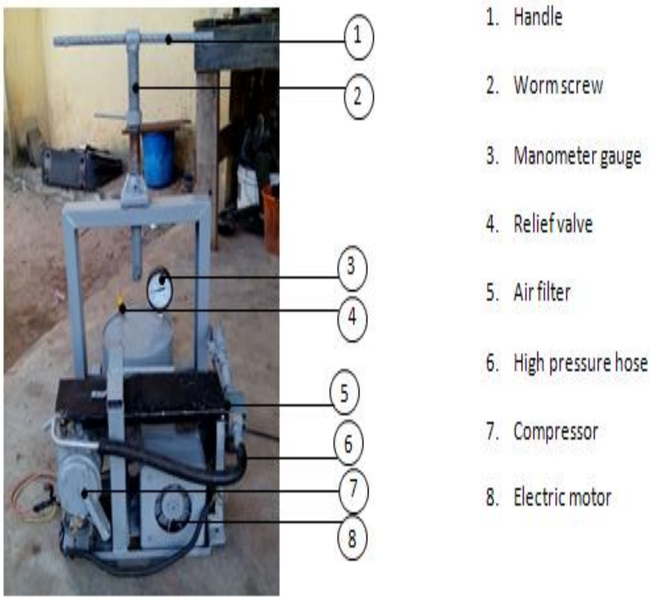


Plate 4: Assembled pressure membrane apparatus with numbered components.

3.0 Operational Analysis of Pressure Membrane Apparatus and Results

Saturated soil samples were placed on a semi-permeable cellophane membrane with microscopic pores. This membrane allows the passage of water from the sample, but retains the air pressure applied to the upper surface of the membrane. A casing was sealed for air-tight onto a base plate by turning the handle of the worm screw. An over pressure was realized as the exerted pressure on the soil water never exceeded the applied air pressure force. Water then drained through the membrane. Upon reaching the equilibrium the samples were removed, weighed, dried and re- weighed using the following procedure;

i. Two pieces of nylon filter cloth, large enough to cover the O-ring in the casing were cut with the calculated length 186.82mm.

ii. Two pieces of cellophane (membrane) foil 2 or 3 cm larger than the base plate were cut and saturated with water for a period of 1 to 3 hours.

i. To ensure proper air tight, the base plate was cleaned with 50% alcohol to avoid contact between the sealing ring and the base plate.

ii. Smoothening the clothes to make sure all traces of air were removed.

iii. Holding the one straight edge, thereby smoothening the two cellophane sheets, then placed the cellophane membrane over the filter cloth to remove air bubbles.

3.1 Sample Preparation

Undisturbed soil samples were usually used for determining pF-curves, because of the major influences of both pore size distribution and soil structure on moisture retention. pF 3.0-4.2 (equivalent to pressures of 1.0-15.5bar) soil water was primarily retained in very small pores, so soil water retention was dominantly influenced by soil texture. The soils were not compressed or deformed within the pressure membrane apparatus to enhance accurate readings, viz.

i. About 1 kg of soil was put into a plastic bag. At least one undisturbed core sample needs to be taken per soil unit, because the bulk density of each soil needs to be known for the calculation of volumetric water content.

ii. The soil samples were moistened with sandy samples about 100 grams with a full glass beaker and carefully add water until the soil becomes saturated. With clayey or loamy clods, care was taken to prevent air entrapment within the aggregates of clayey or loamy clods. Clods are slightly flattened at the bottom side, and put on a piece of cloth, placed in a thin layer of water, allowing to gradually saturate while air escaped.

iii. Sand and loamy samples were left for 3 days and other textured samples for at least 7 days to saturate.

iv. Three to six samples for each soil type were prepared and depending on soil variability in the field, replicates made available at each suction level.

v. Sand and loamy samples were left for 3 days while other textured samples were left for at least 7 days to saturate.

vi. The soil retaining rings were numbered and arranged on the wet nylon membrane.

vii. The rings were filled with saturated soils or clods using a spoon, without disturbing the soil. Ring numbers were recorded with the corresponding soil samples.

viii. An extra ring containing a homogeneous soil or other material was placed with a known moisture retention characteristic, corresponding to that of the soil to be analyzed in the pressure membrane apparatus. If the moisture percentage of the reference sample differs by more than 5% at the test pressure than is expected as a check, the test must be repeated.

ix. The casing was lowered unto the base plate, sealed firmly by turning the handle of the worm screw about 91∘ clockwise.

x. Stop cork B was closed and stop cork A was opened, making sure the pressure has built up sufficiently to encourage escapes from the pressure chamber about 0.5 bar. Worm screw was turned until gas escaped from the pressure chamber and casing completely removed.

xi. The over pressure was reduced before opening the casing, sample ring was removed from the membrane and the soil transferred into numbered moisture boxes with lids, both of known weights. From the weighing balance (sensitivity of 0.01gram) and weights recorded.

xii. Samples were dried in an electric drying oven at 105℃ for 24 hours and cooled to room temperature in a desiccator. The boxes with lids were weighed again to record the dry weight.

xiii. Gravimetric soil moisture content (w) was calculated at the corresponding pF values and converted to gravimetric moisture contents (q) by multiplying with dry bulk density (γd) value.

The over pressure was reduced before opening the casing, sample ring was removed from the membrane and the soil transferred into numbered moisture boxes with lids, both of known weights.

The density of the soil water was assumed as 1g/cm3, and then volumetric soil water content (cm3/cm3) determined as:

$$\boldsymbol{W \times \rho d = Gravimetric\ water\ content \times bulk\ density} \quad (3.1)$$

Weighing balance (sensitivity of 0.01gram) and weights recorded.

Samples were dried in an electric drying oven at 105℃ for 24 hours and cooled to room temperature in a desiccator. The boxes with lids were weighed again to record the dry weight.

Gravimetric soil moisture content (w) was calculated at the corresponding pF values and converted to gravimetric moisture contents (q) by multiplying with dry bulk density (γd) value.

$$\boldsymbol{w = \frac{weight\ on\ soil\ water}{soil\ weight} \times 100\%} \quad (3.2)$$

$$\boldsymbol{\rho d = \frac{(dry\ soil\ weight\ (Excluding\ ring + cloth + elastic\ cloth))}{(Volume\ of\ core\ ring)}} \quad (3.3)$$

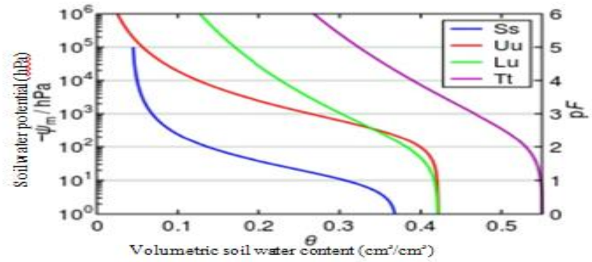
Weight of soil water = Weight of wet sample (including ring + cloth + elastic cloth) - weight of dry sample (including ring + cloth + elastic cloth)

Dry soil weight = Weight of oven-dry sample (including ring + cloth + elastic cloth) - Weight of dry ring + cloth +elastic cloth.

Since, with disturbed soil samples, the volume of the (filled) core ring was unknown, an undisturbed core ring remained sample to be determined for dry bulk density. The bulk density, as determined from corresponding soil cores in Tables 3.1 and 3.2, was used for pF determination and compared with suction potential in Figure 3.2 and calibrated in Table 3.3.

Table 3.1: Determination of corresponding soil cores using soil water grades

Soil water potential (hPa)	Volumetric soil water content (cm^3/cm^3)			
	Sand	Clay	Loam	Silt
10^0	0.35	0.42	0.42	0.6
10^1	0.30	0.42	0.42	0.6
10^2	0.15	0.40	0.42	0.55
10^3	0.05	0.25	0.30	0.45
10^4	0.50	0.15	0.22	0.42
10^5	0.50	0.50	0.18	0.35
10^6	0.50	0.25	0.15	0.30



Ss = sand, **Uu** = loam, **Lu** = clay and **Tt** = silt.

Table 3.2: Determination of soil physical characteristics deduced from pF curves.

Weight (g)					Volume of core ring (V)cm^3					
Ring number	pF	water column (cm) + In potential (hPa)	Wt of wet soil sample+ ring +elastic cloth A	Wt of Dry Soil sample + ring + elastic cloth B	Wtof ring +elastic cloth C	Wt of soil water D=A-B	Wt of dry soil E=B-C	Grav. water content $F=\frac{D}{E}$	Bulk density (g/cm^2) $G=\frac{D}{F}$	Volume water content H=(A)-(B)
1	0.0	1.0	50	27	10	23	17	1.4	16.4	23.0
2	0.4	2.5	45	25	10	20	15	1.3	15.4	20.0
3	1.0	10	40	24	10	16	4	1.2	13.3	16.0
4	1.5	31.6	35	20	10	15	10	1.5	10	15.0
5	1.8	63.1	24	18	10	6	8	0.75	8	6.0
6	2.0	100	20	15	10	5	5	1.0	5.0	5.0

pF 7 corresponding to matrix potential of – 10,000,00 hP_aor – 10,000 bar and a zero moisture content

Volumetric soil water content (cm^3/cm^3) = $W \times \rho d$

where, $W = Gravimetric\ water\ content$,

$\rho d = bulk\ density$

$$w = \frac{weight\ on\ soil\ water}{soil\ weight} \times 100\%$$

$$\rho d = \frac{\textbf{dry soil weight (excluding ring + cloth + elastic cloth)}}{\textbf{Volume of core ring}}$$

Table 3.3: Conversion factors for pF values.

pF value	Matrix potential (hP_a)	Pressure (bar)
2.7	500	0.5
3.4	2500	2.5
4.2	15500	15.5

100hpa= 100cm pressure head = 100cm water column= 0.1 bar= 0.01Pa= 0.01N/m2= pF (log100) = 2.0

3.3 Results

The soil water retention characteristics calculated from volumetric soil water content was plotted on the x-axis, against soil water potential on the Y-axis. Likewise the corresponding pF value was also plotted.

Water retention curve is a relationship between the water content θ, and soil water potentials ψ. This curve is characteristics for different types of soil and is also called the soil moisture characteristic. It was used to predict the soil water storage, water supply to plants (field capacity) and soil aggregate stability. Due to hysteretic effect of water filling and draining the pores, different wetting and drying curves may be distinguished. The general feature of water retention curve Figure 3.2, in which the volume of water content θ is plotted against the matric potential, ψm. At potential close to zero, a soil is close to saturation, and water is held in the soil primarily by capillary forces. As θ decreases, binding of water becomes stronger, and at small potential (more negative, approaching wilting point) water is strongly bound in the smallest of pores, at contact point between grains and as films bond by absorptive forces around particles.

Sandy soils will involve mainly capillary binding, and will therefore release most of the water at higher potentials, at any given potentials, peaty soils will usually display much higher moisture contents than clayed soils. The water holding capacity of any soil is due to the porosity and the nature of bonding in the soil.

The shape of water retention curves can be characterized by several models such as Van Genuchten model.

4.0 Conclusion

The purpose of this work was to proffer an efficient method of determining soil pF values using pressure membrane apparatus. The compressor powered by an electric source, supplied pressure to the membrane, which drained out excessive water from the soil samples. The design and construction took cognizance of being leak free and allowing the plate to be easily assembled and disassembled for both cleaning and soil saturation.

The plate had to be tested on a firm based, so that bending stresses and cracks will be minimized. Monitoring soil pF values is an important parameter used in irrigation scheduling, erosion monitoring/ prediction, hydrological requirements for biomass and estimation of green house gas production for specific soils. Therefore, monitoring soil pF value called for a fast, accurate, reliable and non-destructive instrument which gave way to soil pF values and pressure membrane apparatus, thus enhanced non-destructive method of measurement within few seconds.

5.0 References

Agbakwuru, O.A. Olofin. B. B, and Okere.L E. (2011). Programming Principles; A practical Approach: Auspicious Printing Press, Owerri Imo State, Nigeria. p. 8

Agbakwuru. O. A (2011). Organization of programming language: ByAuspicious printing Press, Imo State, Nigeria. pp 6-7.

Allison. G.B Colville. J. S., and Greacen. E. L. (1983). Soils; An Australian Viewpoint. CSIRO/Academic Press. Australia; p 531

Arora.K.R,(2014).Soil Mechanics and Foundation Engineering. Standard Publishers Distributors, New Delhi p 27.

Bell, J.p, Dean,T.J and Hodnett M.G (2012). Soil Moisture measurement by an Improved Capacitance Techniques, part II, Field Techniques, Evaluation and Calibration Journal of Hydrology, No 93:79-90.

Gardener. C.M.K, Robinson D.A, Blyth. K and Cooper J.D. (2012). Soil Water Content. In: K.A. Smith, and C.E Mullins; Soil and Environmental Analysis; Physical Marcel Dekker, New York pp 1-64.

Gardener. W.H, (1986). Methods of Soil Analysis part 1. Physical and Mineralogical Methods. Soil Science Society of America, inc, Madison, Wisconsin, USA.

Heimovaara J.T and Bouten W.A (1990). A computer controlled 36-Channel

Time Domain Reflectometry System for Monitoring Soil Water Content.Journal No. 26:2311-2316

Johnson .R. Borough C. (1992). Irrigating Tree with Pulp Effluent; A Living tribute to the Late Wilf Crane. ANM Special Liftout, Nos 2 and 21, Vol.15.

Kachanoski R.G Pringle E. and Ward A. (1992). Filed measurement of Solute Travel Time Domain Reflectometry Journal: Soil Science Society of America.

Kramer. J Gullen S.J and Everett, L.G (1992). Vadose Zone monitoring with Neutron Moisture Probe. pp 177-187

Larry G.J, (2014). Principles of farm Irrigation System design. Malabar Florida, U.S.A p44

Ludlow M. M, Sommer K.J Flower. D.J and Ferraris.R (1989). Influence of Root Signals Resulting from Soil Dehydration and High Soil Strength on the Growth of Crop Plant; Journal N0:8-81-99

Michael, A.M, (2014). Irrigation Theory and Practice. New Delhi. pp.339-361

Michael and Ojha, (2013). Soil Moisture measurement by an Improved Capacitance Techniques, part II, Field Techniques, Evaluation and Calibration Journal of Hydrology, No 93:79-90.

Robert.E. Cassel D.K and Sneed, R.E, (2014). Irrigation Scheduling, Monitoring Methods and devices. By North Carolina Extension Service, USA.

Topp.G.C Davis.J.L.and Annan A.P, (1980). Electromagnetic Determination of Soil Water Content; Measurement in Coaxial transmission Lines. Water Resources Journals N0:16:574-582

Whally. W,R. Dean T. J and Izzard. P. (1992). Evaluation of the capacitance Techniques as a Method of Dynamically Measuring Soil Water Content Journal of Agricultural Engineering Research, No: 52:147-155

White,I. and Zegelin S.J, (2015). Electric and Dielectric Methods for Monitoring Soil Water Content in Vadose Zone Characterization.