DESIGN AND DEVELOPMENT OF TENSIO-EMITTER

by

JISHITHA RAVINDRAN

(2010 – 18 – 104)

THESIS

Submitted in partial fulfillment of the
requirement for the degree of

MASTER OF TECHNOLOGY
IN
AGRICULTURAL ENGINEERING
(SOIL AND WATER ENGINEERING)

Faculty of Agricultural Engineering & Technology
Kerala Agricultural University

DEPARTMENT OF LAND &WATER RESOURCES AND CONSERVATION ENGINEERING

KELLAPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

TAVANUR - 679573

2012

DECLARATION

I hereby declare that this thesis entitled **"DESIGN AND DEVELOPMENT OF TENSIO-EMITTER"** is a bonafide record of research done by me during the course of research and the thesis has not previously formed the basis for the award to us for any degree, diploma, associateship, fellowship or other similar title of any other university or society.

Place: Tavanur

Date: **Jishitha Ravindran**

Vishnu, B.
Assistant ProfessorDept. of Land and Water Resources
and Conservation Engineering
KCAET, Tavanur

Date:

CERTIFICATE

Certified that this thesis, entitled "**Design and Development of Tensio-Emitter"** is a record of research work done by **Jishitha Ravindran** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associate ship to her.

Tavanur

Vishnu, B
Major Advisor

CERTIFICATE

We the undersigned members of the advisory committee of **Jishitha Ravindran (2010-18-104)** a candidate for the degree of **Master of Technology** agree that this thesis entitled “ **Design and Development of Tensio-Emitter”** may be submitted by **Jishitha Ravindran (2010-18-104)**, in partial fulfilment of the requirement for the degree.

Vishnu, B.
Assistant Professor
Department of Land and Water Resources &Conservation Engineering
KCAET, Tavanur
(Major Advisor)

Dr. E. K. Kurien
Associate Professor and Head
Department of Land and Water
Resources &Conservation Engineering,
KCAET

Dr. K. V.Levan
Associate Professor
Department of Irrigation and Drainage
Engineering, KCAET

Dr.Jayan, P. R.
Associate Professor and Head
Department of Farm Power Machinery
and Energy, KCAET

Dr. V. Anil Kumar
Reader and Head
Department of Mathematics,
University of Calicut

ACKNOWLEDGEMENT

I would like to avail this opportunity to express my deep sense of gratitude and heartfelt thanks to **Er. Vishnu, B**, Assistant Professor, LWRCE, KCAET, Tavanur and Major Advisor for his guidance, suggestions and advice throughout the research work and in preparation of this thesis report.

I am thankful to **Prof. M. Sivaswami,** Dean (Agri. Engg.) for the co-operation extended towards the completion of this work. I wish to express my gratitude to members of the advisory committee: **Dr. E. K. Kurien**, Assoc. Prof., Dept. of LWRCE, **Dr. Levan, K. V**, Assoc Prof., Dept. of IDE and **Dr. Jayan, P. R**, Assoc. Prof. and Head, Dept of FPME of KCAET, Tavanur and **Dr. Anilkumar, V.**, Reader and Head, Dept. of Mathematics, Calicut University for their support. The help rendered by **Dr. Abdul Hakkim, V. M**., Associate Professor and **Er. Renuka Kumari, J.**, Assoc. Prof., RARS Pattambi is gratefully acknowledged.

I would like to express my regards to the technicians of the KCAET workshop, especially **Manohar Krishna** and also **Vasudevan**, farm labourer, for their support during the course of my work. I am short of words to express my regards to my classmates, especially **Er. R. Madhana Supriya** for their great support. I am also grateful to **Er. Nitha, K**, and **Er. Drisya, J.** of TNAU, and **Dr. Cibin Raj** of Purdue University, USA and **Er. Prasanth, V. Krishna** for their help and support.

I am also thankful to Kerala Agricultural University for the institutional support and the fellowship awarded to me during the course of this work. I would like to thank all those involved, directly or indirectly, and also the students and staff of KCAET, Tavanur in making this project successful. I am forever indebted to my parents and my husband for their immense support and encouragement to complete my work. Above all I bow my head before God Almighty for His blessings.

Jishitha Ravindran

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

SYMBOLS AND ABBREVIATIONS

° C	Degree Celsius
atm	Atmosphere
B. C	Before Christ
cm	Centimeter
DC	Direct Current
et al	and others
Fig.	Figure
h	Hour
h	Pressure Head,
ha	Hectares
KCAET	Kelappaji College of Agricultural Engineering andTechnology
kPa	Kilo Pascal
l	Litres
m	Metre
MAD	Management Allowable Deficit
mm	Millimetre
MPa	Mega Pascal
n	Curve shape parameters
POT	Potential tensiometer

RETC	Retention Curve Program for Unsaturated Soils
S_e	Effective saturation
SWCC	Soil water characteristic curve
T.D.R	Time domain reflectometry
V	Volts
α	Curve shape parameters
θ	volumetric moisture content
θ_r	Residual water content
θ_s	Saturated water content

Introduction

Chapter I

INTRODUCTION

Irrigation is the main practice that utilizes major part of water in an agricultural country like India. In a monsoon climate and an agrarian economy, irrigation has played a major role in the production process. There is evidence of the practice of irrigation since the establishment of settled agriculture during the Indus Valley Civilization. India is endowed with a rich and vast diversity of natural resources, water being one of them. Its development and management plays a vital role in agriculture production. Integrated water management is vital for poverty reduction, environmental sustenance and sustainable economic development. National Water Policy (2002) envisages that the water resources of the country should be developed and managed in an integrated manner using irrigation systems that apply water more uniformly and in limited amounts to avoid water stress in plants and to prevent excessive drainage. The main reason behind is that over-application of irrigation water decreases water use efficiency and increases nutrient leaching, which results in reduced nutrient availability and increases groundwater pollution. Low pressure irrigation methods, such as drip or trickle systems, apply water more precisely to plants. These micro-irrigation systems have become wide spread in high-value horticultural and nursery crops and plays a major role in reducing the water required in agricultural and horticultural crops, but has highlighted the need for new methods of accurate irrigation scheduling and control (Jones, 2004).

When it comes to irrigation scheduling tensiometers are devices that are widely used to schedule and also control irrigation by measuring the soil water potential. Commercial tensiometers generally consist of a plastic tube closed at the bottom by a water-permeable body usually porous ceramic cup, a pressure measuring device commonly vacuum gauge, and a water refilling arrangement at the top. The tube is filled with de-aerated water and the water permeable end is inserted into the soil with the tube usually in a vertical orientation. Water passes through the porous ceramic cup in either direction, depending on the water content of the soil. Water moving out of the tube into a drying soil creates a negative pressure head in the tensiometer. For a saturated soil, tensiometer readings are near 0 kPa and can be as high as -80 to -100 kPa for dry soils.

Tensiometer measurements are useful in deciding when to irrigate because they give a continuous indication of soil water status. They do not indicate how much water should be applied. The decision to irrigate is made when the average tensiometer reading exceeds a given critical value. The critical values are different for specific soil types, crops, and stage of crop growth. At critical stages of crop growth, lower values of suction are used, resulting in irrigations being scheduled more frequently. The critical values are also functions of economic considerations like the variations in price of the commodity. A moisture characteristic curve specific for irrigated soil is used to determine the amount of water to be applied. The depth of irrigation water applied is so adjusted to restore the root zone to field capacity level. In large irrigation systems control devices are often employed to provide adequate supply of irrigation water.

A control device is an integral part of any irrigation system. It is an essential device to apply water in the required quantity and at the right time to achieve high level of water application efficiency and conservation of energy (Zazueta, 1993). The control devices fall under two categories namely, pneumatic and hydraulic. In pneumatic controllers, a diaphragm acts as a pressure sensor. The diaphragm activates an electric current or a pilot valve for switching the flow of irrigation water. A commercially available control system uses magnetic switches which are positioned on the face of a vacuum-gauge indicator needle and either activate or deactivate an electrical irrigation control valve. In a hydraulic system, the controller and valves are connected via small plastic tubes approximately 4 mm in diameter. The controller opens the tube connected to the valve, allowing the valve to open. Most modern systems employ electromechanical or electronic controllers. In this scenario, the controller is connected to an electrical circuit that operates a solenoid valve. When the solenoid is actuated, the water above the diaphragm is relieved and the valve opens. The main components of an automated irrigation include a sensor, controller and an actuator.

Automatic irrigation helps the farmers to reduce the labour requirement for irrigation by applying the correct amount of water for the crop can be applied at the right time using automated irrigation system. Automated irrigation technologies are adopted mostly in large scale irrigation. This scenario demands simpler automation systems with sufficient accuracy in small scale farms, gardens and under protected cultivation. If automation is possible with a simpler system with sufficient accuracy in small scale gardening or pot irrigation, then it will be an advantage that the owner need not worry about watering plants even when he is away. But presently no such automation techniques are popularized.

It is seen that the automated irrigation controllers are very sophisticated, expensive and mostly applicable in the case of large scale cultivation of high value crops. Development of efficient, low cost irrigation controllers suitable for small scale applications for small green houses kitchen gardens and for potted plants are not available is felt as a need of the hour. Review of previous research showed that this problem can be solved using a tensiometer as an irrigation controller.

Tensiometers can do the works of sensor controller and valve simultaneously and can act as a substitute for complex devices. Hence there is a need to develop techniques that use accurate amount of water just sufficient to meet the water requirement. It’s a known fact that over application of water does not do any good to the plant but does effect negatively. There are many methods that are water efficient and are effectively used in the field. But this study aims at the development of an emitter that works merely on the soil metric potential that does not require an external support for its working and that can be effectively used in small scale irrigation like the kitchen garden and potted plants.

The present thesis work is undertaken with the general objective of design and develops a TENSIO-EMITTER that automatically controls irrigation based on the matric potential developed in the crop root zone. The specific objectives are:

- To analyse the state of art in automatically controlled emitter mechanisms.
- To explore different mechanisms for the soil moisture tension controlled emitters.
- To develop a Tensio-Emitter which can automatically control the irrigation based on the soil moisture tension.
- To evaluate the working of the developed emitter with respect to its ability to automatically control the irrigation according to the soil moisture level.

Review of Literature

Chapter II

REVIEW OF LITERATURE

2.1 Development time line of tensiometer

One of the most useful devices in monitoring soil moisture status is the tensiometer. The earliest account of a tensiometer or a tensiometer-like device was reported by Livingston in 1908. It used all the elements of a modern tensiometer to control the soil water status of a potted plant. But the first robust design for field applications is attributed to Lorenzo A. Richards, one of the 20th century's most influential minds in the field of soil physics during the early 1920s (Or, 2001). The tensiometer was developed from the idea of using a semi-permeable, porous ceramic material to balance the pressure potential inside the tensiometer tube against the matric potential of the soil outside; once equilibrium is established, the matric potential of the soil is equivalent to the pressure potential inside the tensiometer. The measurement of the matric potential of the soil is very useful because it is directly related to the ability of plants to extract water from soil. Irrigators often use tensiometers for irrigation scheduling because they provide direct measurements of soil moisture status and they are easily managed. In addition, tensiometers can be automated to control irrigation water applications when the soil water potential decreases to a predetermined critical value (Smajstrla and Harrison, 1998).

2.2 Construction of tensiometer

A tensiometer consists of a porous cup, connected through a rigid body tube to a vacuum gauge, with all components filled with de-aerated water. The porous cup is normally constructed of ceramic material because of its structural strength as well as permeability to water flow. The body tube is normally transparent so that water within the tensiometer can easily be seen. A Bourdon tube vacuum gauge is commonly used for water potential measurements. The vacuum gauge can be equipped with a magnetic switch for automatic irrigation control. A mercury manometer can also be used for greater accuracy, or a pressure transducer can be used to automatically and continuously record tensiometer readings (Smajstrla and Harrison, 1998, Richards, 1941).

2.3 Irrigation scheduling using tensiometer

The tensiometer constructed by Richards (1962) was equipped with a gauge assembly that eliminated the need for removal of complete tensiometer from the soil for repair calibration etc. It also provided the versatility of type of installation as to depth and placement of tensiometers by the use of several soil tubes with a lesser number of mounted gauges. Many modifications are made in the conventional tensiometers to be effectively used for the scheduling purpose.

A portable tensiometer was developed by Skaling (1978) for soil moisture measurement. Capillary tubing was contained within the interior of the porous tip which connects the porous tip to the adjustable volume chamber and to the vacuum gauge to form a sealed, normally water filled system, and the use of minimal volume of water in the instrument minimizes errors due to changes in the temperature to which the instrument is subjected.

Smajstrla and Koo (1986) used tensiometers to automatically schedule irrigation of citrus in a field irrigation project by using commercially available magnetic switching tensiometers that initiated irrigation when the soil moisture level dropped to pre-set levels. The controllers apply predetermined amount of water in each irrigation. The system responded well when they were located in the citrus root zone.

A hydraulic tensiometer was designed by Browne (1990) which includes a pressure sensitive electrical switch which acts to control an irrigation system in response to changes in matric water potential. Three chambers were defined in the tensiometer by moveable diaphragms. Two of the chambers were not in communication with the tensiometer probe, but are interconnected by a passage way. Flow through the passageway was controlled by an electrically operated valve.

Smajstrla and Lucascio (1990) carried out a two year study by scheduling irrigation for tomatoes with tensiometers to determine the effect of irrigation scheduling practice in Florida. They reported that the yields were significantly greater and the marketable fruits increased by 50% by the first year. Hence tensiometers can be effectively used for irrigation scheduling which not only increases the yield but also conserves water.

An automated irrigation system was developed by Luthra *et al.* (1997) that helped in scientific irrigation scheduling. He reported that automatic control of water application at predefined soil water tensions is an effective irrigation scheduling technique. This was achieved through an indigenously developed auto irrigation system. In this system soil water tension is sensed through a modified manometer type tensiometer. The design provides control of irrigation at the predefined soil water tensions and a pre-programmed timer operated with a 12V D.C. storage battery.

Warrick *et al.* (1998) reported that pressure fluctuations in tensiometers in response to temperature changes generally fall between two simplified, limiting cases. The first limiting case assumes that the tensiometer cup is impermeable for water. This leads to very high fluctuations as air and soil temperatures change. For a cyclical temperature of 35 ± 15°C, variations in water pressure inside the cup can be 67 cm water head. For the second limiting case the water moves freely between the tensiometer and the soil, which leads to more stable readings, within 61 cm for the above 15°C fluctuation. While cup impedance was found to be a negligible factor for all cases considered, the analysis presented here suggests that conductivity of the soil immediately around the cup is the main factor governing temperature-induced pressure fluctuations inside the cup.

Tensiometer is an instrument widely used for scheduling irrigation by measuring soil moisture tension according to Majumdar (2000). The tension recorded by the tensiometer is used to determine the soil water content by referring to the soil water characteristic curve.

The switching tensiometers at 15 kPa set point performed the best reducing up to 73% of water use compared with commercial farm practice, and 50% with respect to the 100% recommended crop water needs treatment according to Carpena *et al.* (2003). Routine maintenance like refilling and pumping were critical for reliable operation of the switching tensiometers, especially on the driest treatment of 15 kPa where twice weekly routine maintenance is recommended.

A self-compensating tensiometer was designed by Hubbell and Sisson (2003) that could determine below grade soil moisture potential of earthen soil independent of changes in the volume of water contained within the tensiometer chamber. It comprises of a body having first and second ends, a porous material defining first end, a liquid within the body, a transducer housing submerged in the liquid such that a transducer sensor within the hosing is kept below the working fluid level in the tensiometer and in fluid contact with the liquid and the ambient atmosphere.

It was reported by Thalheimer (2003) that the fluctuation of the height of the water column inside tensiometers constitutes a source of systematic error in the measurement of soil water potential. The influence of the fluctuating water column can be strongly reduced by measuring pressure in a confined air space close to the tensiometer tip. A simple technique of inserting a lower air space connected to the pressure sensor was successfully tested in laboratory and was performed on a tensiometer of 1m length with an applied pressure range from 0 to -80 kPa.

Grover *et al.* (2004) provided a method for collecting data regarding the metric potential of a media which included a tensiometer having a stainless steel casing and a tip portion which includes a wetted porous stainless steel membrane through which the matric potential of a media is sensed.

Bakker *et al.* (2007) reported that tensiometers filled with a polymer solution instead of water are able to measure a larger range of soil water matric pressures than a water filled conventional tensiometers, which have limitation up to -0.85 atm. Polymer tensiometer appears very attractive for field applications because of its much wider measurement range and fast pressure response.

According to Dukes (2007) calculated amount of water in the plant root zone has been recommended for many years as a basic irrigation management strategy to determine when to irrigate and how much to irrigate and the soil moisture based controllers have the potential to reduce residential irrigation consumption.

An experimental device to monitor the field soil suction using a miniature tensiometer was developed by Cui *et al.* (2008). This device consisted of a double tube system that ensured a good contact between the tensiometer and the soil surface at the bottom of the testing borehole. This device was used to monitor the soil suction at a site in France. The measurement was performed at two depths (25 and 45 cm) during two months .The recorded suction data are analysed by comparing with the volumetric water content data recorded using TDR probes as well as the meteorological data. A good agreement between these results was observed, showing a satisfactory performance of the developed device.

Lourenco *et al.* (2008) reported that the linear extrapolation of the calibration of high suction tensiometer from the positive to the negative range is sufficiently accurate provided that calibration is done under conditions that closely match the conditions in which the tensiometer will be used. Owing to structural differences between tensiometers, and also to suction induced calibration hysteresis, at least one check on the accuracy of the extrapolated calibration equation over a range of negative pressure should be performed, even if at low values of suction.

According to Pardossi *et al*. (2009) crop irrigation uses more than 70% of the world's water, and thus, improving irrigation efficiency is decisive to sustain the food demand from a fast-growing world population.

According to Ploeg *et al.* (2009) measuring soil water potential is crucial to characterize vadose zone processes. Water-filled tensiometers only measure until approximately −0.085MPa, and indirect methods may suffer from the non-uniqueness but recently developed polymer tensiometers (POTs) are able to directly measure soil matric potentials until the theoretical wilting point. By minimizing the volume of polymer solution inside the POT while maximizing the ceramic area in contact with that polymer solution, response times drop to acceptable ranges for laboratory and field conditions.

Design and construction of an automated irrigation system was presented by Nzokou *et al.* (2010) that provides water on demand at two Christmas tree farms. Elements of the system included data logging equipment, an irrigation controller, and a set of tensiometers used as trigger for the irrigation of the various zones. The system generally functioned properly with irrigation events starting immediately as soon as the soil water tension reached the pre-determined threshold for each irrigation zone.

It is seen that the tensiometer is a very useful device in irrigation scheduling and it keeps a continuous check on the major portion of available water in the soil. But the main thing to be noted is that a tensiometer does not provide direct measurement of soil water. To know the actual water content a soil moisture characteristic curve is to be constructed for the field in which tensiometer has been installed (Majumdar, 2000).

2.4 Soil moisture characteristic curve

The soil-water characteristic curve (SWCC) gives the relationship between the amount of water in the soil and soil suction, matric suction at low suction and total suction at high suction. Many properties of a partially saturated soil such as the coefficient of permeability, shear strength and volume strain, pore size distribution, the amount of water contained in the pores at any suction, can be obtained from the SWCC. The water holding capacity of any soil is due to the porosity and the nature of bonding in the soil.

A general equation was proposed by Fredlund and Xing (1994) for the soil water characteristic curve. A general form of relationship between water content and suction was developed based on the assumption that the soil moisture characteristic is dependent on the pore size distribution of the soil. The equation provided a good fit for sand, silt and clay over the entire range of 0 to 106 kPa.

The soil water characteristic curve is of great value in estimating unsaturated soil properties as reported by Fredlund *et al.* (1998). It defines the degree of saturation corresponds to a particular suction in the soil and becomes measure of the pore size distribution of the soil.

A new class of equation was developed by Gitirana and Fredlund (2004) to overcome the difficulty of sensitivity analysis and statistical assessment of SWCC parameters as traditional representation of these equations do not individually correspond to clearly defined soil properties. The new class of equation represented both unimodal and bimodal soil-water characteristic curves and was defined by parameters that have physical meaning and that are independently related to shape features of the SWCC. The proposed equation could make the treatment of SWCC data easier, and statistical analyses on a large amount of data will benefit from the use of an equation whose parameters are mathematically independent

The various factors influencing the soil moisture characteristic curve were investigated by Zhou and Yu (2005). They studied the effects of void ratio, initial water content, stress state and high suction in their work revealing that water content and stress state are more important than the other effects; but that the influences tend to decrease when suction increases.

2.5 Hysteresis effect in soil water characteristic curve

Soil holds more water at a given tension during desorption than during sorption. This phenomenon is known as hysteresis. The hysteresis loops produced in the tension-moisture content relationship when soil is cyclically wetted and dried. Due to hysteretic effect of water filling and draining the pores, different wetting and drying curves may be distinguished.

The SWCC of a soil is hysteretic and the measurement of a complete set of hysteretic curve is extremely time consuming and therefore quite costly. Hence study was carried out by Pham *et al.* (2003) to find a simple model for predicting or estimating the hysteretic SWCC is needed. The study showed that the boundary wetting curve predicted by Feng and Fredlund model is quite close to the laboratory-measured results. At high soil suctions, the predicted boundary wetting curve is slightly overestimated which is due to insufficient measured data points.

The magnitude of the hysteresis of the soil, according to Yang *et al.* (2004), ranges from 0.2 logarithm cycles of suction for the fine sand to 1.1 logarithm cycles of suction for the clayey sand near the inflection points on the curves. They also added that hysteresis in the SWCCs indicates that the volumetric water content in the soil is not unique at a specific matric suction value but is related to the wetting and drying history of the soil. The SWCC of a uniform soil has a steeper slope than that of a less uniform soil.

Elmaloglou and Diamantopoulos (2008) investigated the infiltration and redistribution of soil moisture under surface drip irrigation considering hysteresis in loamy sand and silt loam of different texture. The effects of continuous versus intermittent application of water at 1, 2 and 4 l/h to the soils were evaluated in terms of wetting front advance patterns and deep percolation under the root zone. For this purpose, a cylindrical flow model incorporating hysteresis in the soil water retention characteristic curve, evaporation from the soil surface, and water extraction by roots was used. The results showed that, compared with continuous irrigation, pulse irrigation slightly reduced the water losses under the root zone in cases with and without hysteresis. Also, at the total simulation time, in both types of irrigation, hysteresis reduced significantly the water losses under the root zone. Finally, the effect of hysteresis was found to be greater at higher discharge rate (4 l/h) and consequently at higher water content at the soil surface.

2.6 RETC for construction of Soil moisture characteristic curve

RETC stands for retention curve is a computer program which may be used to analyse the soil water retention and hydraulic conductivity functions of unsaturated soils. These hydraulic properties are key parameters in any quantitative description of water flow into and through the unsaturated zone of soils.

RETC was used successfully by Yates *et al. (*1992) to analyse thirty six water retention curves from twenty three different soils. They further stated that RETC offers an attractive and efficient method for predicting the unsaturated hydraulic conductivity from water retention data when measured conductivities are not available.

Soil hydraulic parameters in El-Tina Plain were estimated by Galal (2004) using RETC program. He concluded that it can be successfully used to estimate soil hydraulic functions and gave high accuracy for estimating the hydraulic functions.

RETC software program was used by Looms (2003) to inversely fit a continuous retention curve to investigate the dynamic effects on unsaturated hydraulic parameters and this way the characteristic parameters determining the shape of the curve was found.

Huang *et al.* (2004) reported that hysteresis model based on van Genuchten's soil-moisture relationships yields a series of closed-form relationships in which two shape factors α and n are determined from the main drying and wetting curves. The compared results indicated that model was simple, accurate and effective in constructing the series of wetting and drying scanning curves.

2.7 Irrigation control systems

Irrigation controllers have been available for many years in the form of mechanical and electromechanical irrigation timers. These devices have evolved into complex computer-based systems that allow accurate control of water, energy and chemicals while responding to environmental changes and development stages of the crop. A controller is an integral part of an irrigation system. It is an essential tool to apply water in the necessary quantity and at the right time to sustain agricultural production and to achieve high levels of efficiency in water, energy and chemical uses (Zazueta *et al.,*1993). Controlled irrigation is of great importance to the plants as it provides the right amount of water to plants which results in proper aeration in the root zone thus creating favourable conditions for the plants. The main parts of an automated system include:

2.7.1 Sensor

It is the main component which senses the real time soil moisture status. Most times the sensor used is a tensiometer, granular matric blocks, electro-magnetic probes etc. They provide the basic data that drives an automatic control system. Hence their working principles are to be thoroughly understood (Zazueta, 1993, Dukes *et al,* 2008, Dukes, 2009).

2.7.2 Controller

The controller or timer is an electronic device connected to the sensor which runs the irrigation system. They are programmable as when to start and stop irrigation and how often the irrigation is to be done. Electromechanical controllers are also available that use an electrically driven clock and mechanical switching using gear arrays to activate the irrigation stations. These types of controllers are generally very reliable and not too sensitive to the quality of the power available (Zazueta, 1993, Dukes, 2009).

2.7.3 Valves or Actuators

These are devices that allow the water to be conveyed to the plant. They will be connected to the controller. Valve opening and closing is determined by the controller. Different valve actuation design are used to operate the valves are diaphragm type, piston type, electric thermal motor type. The most common type of automatic valve is the diaphragm type. The diaphragm is moved from a closed to open position by using the action of a spring and water pressure difference. Piston valves employ a moving piston to open and close valves according to the pressure difference. Electric thermal motor valves use a thermal motor to directly operate the valve (Zazueta, 1993, Haman and Zazueta, 1998).

Recently computerized irrigation controls are available that remotely controls irrigation from a distant area on a large scale. The analogue-to-digital converter (ADC, A/D or A to D) will be directly connected to the computer system which converts the analogue electrical signals resulting from the sensors to digital data (Boman *et al.,* 2002). The control mechanism of irrigation is represented in the Fig. 2.1.

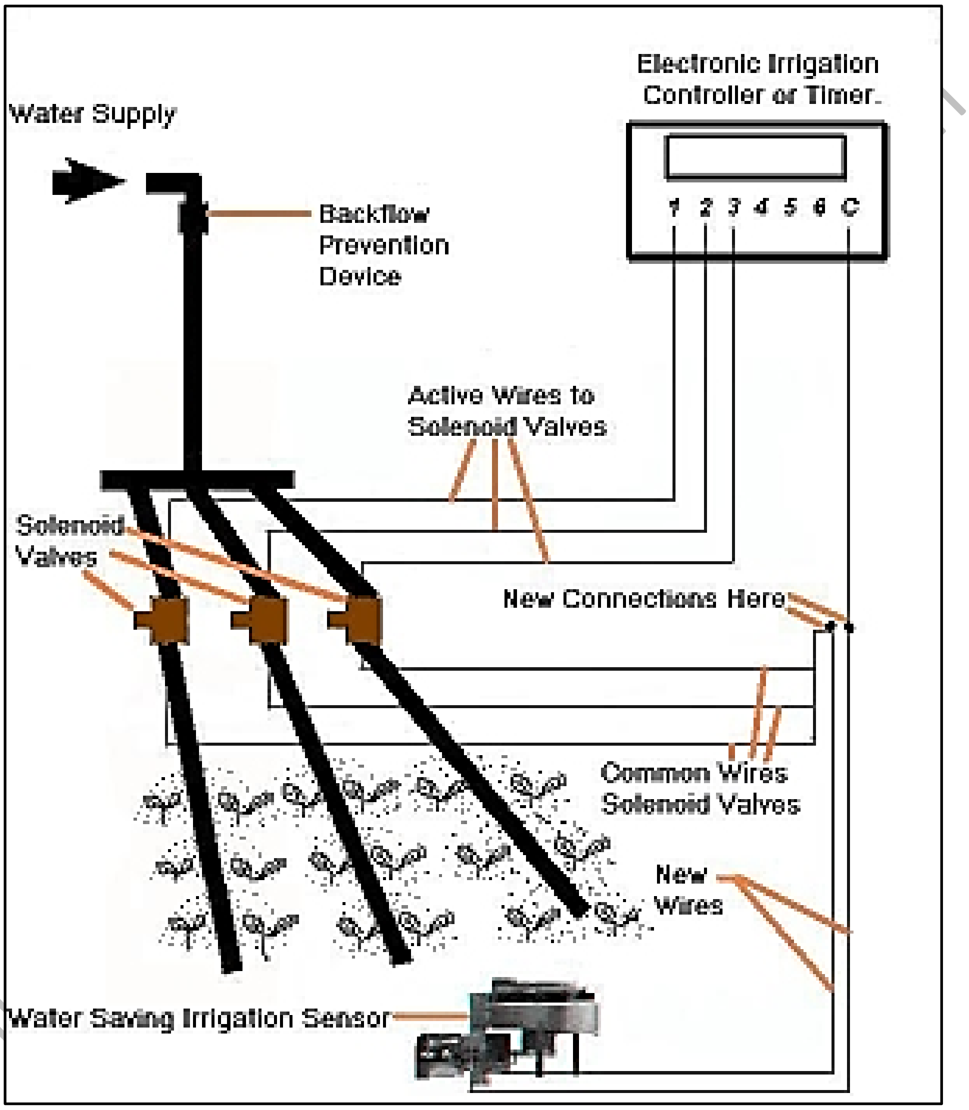

Fig. 2.1. Computerized irrigation control system

Materials & Method

Chapter III

MATERIALS AND METHOD

The goal of any irrigation controlling mechanism is to make the most efficient use of water and energy by applying the right amount of water to the plant at the right time and in the right place. They are more reliable and extensively reduce the labour requirement. But it is seen that the automated irrigation controllers are very sophisticated and mostly applicable in the case of large scale cultivation only. Hence this study is mainly intended to develop a system called Tensio-Emitter, which is simple in operation and has a minimum number of parts and works without any external power. This chapter includes the study of soil characteristics of the location of study and the development of the Tensio-Emitter.

3.1 Location

The study was conducted at KCAET, Tavanur situated at 10º 52’ 30” North latitude and 75º 59’ East longitude.

3.2 Characteristics of soil used for the study

Potting mixture for conducting the experiment was made by mixing soil, sand and cow dung powder in the ratio 2:1:1. The bulk density of the soil was measured using the core cutter method.

The soil type of the potting mixture was determined by Sedimentation Test also known as jar test (Whiting *et al.,* 2011). Soil sample is placed in a container with clean water. The container is shaken for 1-2 minutes. After 1 minute, the sand particles will settle down while the loam particles settle down after one hour. Clay particles finally settle down after one day. Read the depth of sand, silt and clay after settlement in the bottle, work out the percentage of these three components, and the soil texture class is found out by triangulating the formation in the soil texture triangle (Fig.4.1).

3.2.1 Soil moisture characteristic Curve

The soil moisture characteristic curve was plotted to find out the tension corresponding to Management Allowed Depletion (MAD). It is also known as maximum allowable depletion, manageable allowable deficiency, allowable soil depletion or allowable soil water depletion. This is the portion of water that is allowed for plant use prior to irrigation based on plant and its management conditions. The soil water characteristic curve for a soil is defined as the relationship between water content and the suction of the soil (Fredlund and Xing, 1994). These curves are important as to determine the amount of water to be applied in case of tensiometric irrigation scheduling. SWCC is an important hydraulic property related to size and connectedness of pore spaces; hence strongly affected by soil texture and structure, and by other constituents including organic matter. For plotting the characteristic curve the suction experienced in the soil at different moisture content are to be found out. It was known that the SWCC experiences hysteresis when it comes to wetting cycle from the drying. First the drying curve was found out using the pressure plate apparatus manufactured by Soil Moisture Equipment Coorperation (USA). The SWCC for the wetting cycle was found using the capillary rise open tube method (Yang *et al.,*2004).

3.2.2 Drying curve

The soil moisture characteristic curve for drying cycle can be obtained by simulating the required pressure in the pressure plate apparatus and finding the respective moisture content. Pressure plate was introduced in the 1930s by L.A. Richards. It doesn't actually measure the water potential of a sample. Instead, it brings the sample to a specific water potential by applying pressure to the sample and allowing the excess water to flow out through a porous ceramic plate. When the sample comes to equilibrium, its water potential will be equivalent to the pressure applied. Pressure plates are typically used to make soil moisture characteristics (Tuller & Or, 2003). A completely saturated soil samples are filled in the containment rings and are kept on the porous ceramic plate and the lid is closed and tightly screwed. Once the soil samples reached specific water potential under pressure (this requires a minimum of 48 h) the sample is removed from the plate and the moisture content was measured by gravimetric method. In this manner the moisture content of the sample at different pressure was obtained and tabulated (Table 4.2). The soil moisture characteristic curve is to be drawn using these values. Since the curve experiences hysteresis the SWCC of the wetting cycle is also to be found out.

3.2.3 Wetting curves

The wetting SWCC was obtained using a capillary rise open tube. In the capillary tube test, soil is compacted in an open tube at a target dry density and placed in a tray with a water table maintained at the bottom of the tube .The top of the tube is covered to prevent evaporation. Water in the tray starts to move into the soil as soon as the tube is placed in the tray. After some time, equilibrium of the capillary water in the tube is reached. Soil samples can then be taken from various levels in the tube and oven dried to determine the water content. The height of a soil specimen above the water table is assumed to be equal to the capillary head (or negative pore-water pressure head) at that point. The magnitude of the negative pore water pressure head is equal to the matric suction head, as the air pressure in the tube is atmospheric. The plot of water content versus matric suction gives the wetting SWCC of the soil (Yang *et al.,*2004). In this study, tube of 100 mm in diameter and 350 cm in length were used. Capillary tubes of soil were allowed to wet for 50 days (Plate 3.1). This period was considered sufficient for the soil tubes to reach equilibrium. The moisture content of the soil inside the tube was taken at various intervals and tabulated (Table 4.7) so as to obtain the plotting points for the SWCC wetting cycle.

3.2.4 Hysteresis effect of soil moisture characteristic curve

The soil moisture characteristic curves are subject to hysteresis, meaning that they change appearance according to the process path in which they are obtained, i.e. different curves are achieved when the soil is being drained (drying) or wetted. Hysteresis is caused by several factors: entrapped air during the wetting cycle, different contact angles of the liquid when wetting and draining and the so-called ink-bottle effect (Fig.3.1) where non-uniform capillary tubes give rise to different levels of saturation, i.e. water cannot rise due to large capillarity during wetting process (Looms, 2003). For plotting the curve we need the moisture content of the sample in both wetting and drying cycle in the same pressure range. But it could not be obtained because of the practical difficulty to erect the tube filled with soil at such high length. Thus the values are to be extended using some means so as to obtain both the curves in the same range of pressure. Thus in this case RETC software was used to analyze the data obtained from the capillary rise experiments to derive the hysteresis graph.

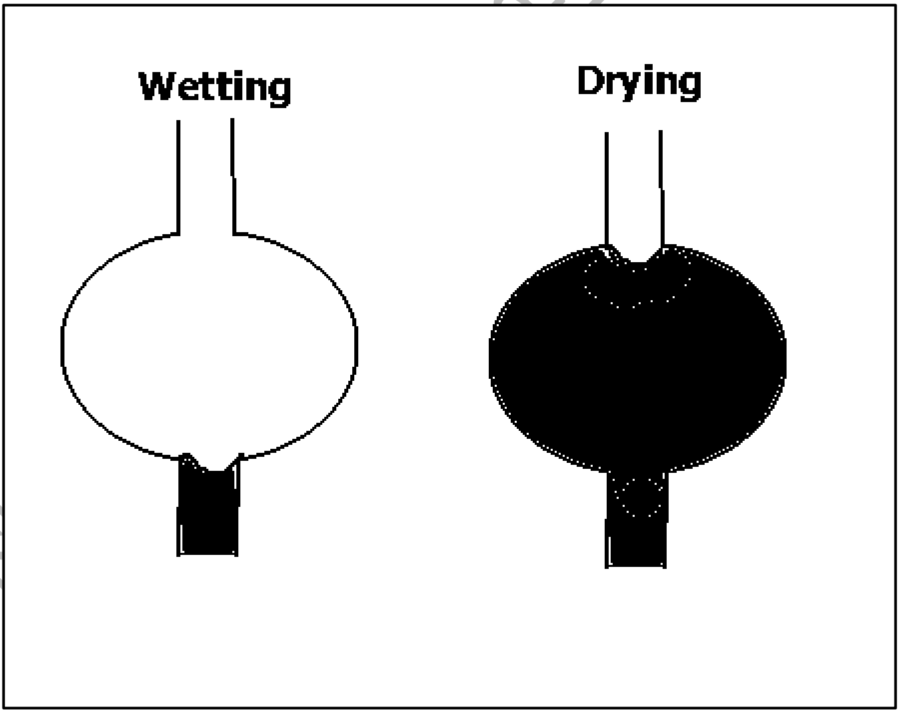

Fig. 3.1 Ink-bottle effect

Plate 3.1 Experimental setup for determining the Wetting Curve

3.2.5 Retention Curve (RETC) Program for Unsaturated Soils

RETC is a computer program used for the analysis of the soil water retention curve and hydraulic conductivity of unsaturated soils. These hydraulic properties are key parameters in any quantitative description of water flow into and through the unsaturated zone of soils. The program uses the parametric models of Brooks-Corey, van Genuchten-Mualem, the lognormal distribution model of Kosugi and the dual-permeability model of Durner (van Genuchten, 1991). The most popular of these models is the van Genuchten-Mualem model.

This model assumes that the main drying and wetting retention curves can be described accurately by the expression

$$S_e = \theta -$$

$$S_e = +$$

Where S_e denotes the effective saturation, θ represents the volumetric moisture content, h is the pressure head, θ_s and θ_r denote the saturated and residual water contents respectively, α and n represent the curve shape parameters and m =1-1/n.

The pressure and corresponding moisture content obtained from the experiment was fitted to the van Genuchten-Mualem equation using RETC and a good fit was obtained between the observed values and that obtained from Van Genuchten-Mualem equation (Table 4.6, Figure 4.2). The same procedure was carried out for the wetting curve data and the SWCC for the wetting cycle was obtained (Table 4.10, Fig. 4.3). Both the graph was combined to get the SWCC which showed the hysteresis (Fig. 4.4).

3.3 Development of the Tensio- Emitter

3.3.1 Considerations

The main aim of the study was to develop an emitter that operates or activates depending upon the moisture condition of the soil. The emitter needs to start watering when the soil become dry enough as decided by MAD thus irrigating the plant and restoring the moisture that was depleted and stop watering when field capacity is reached. The system also has to be simple and easy to install and use. The system is mainly intended for pot irrigation.

3.3.2 Components of the Tensio-Emitter

In any automatic irrigation control system there are mainly three parts: a sensor, a controller and an actuator (valve). The sensor of the proposed Tensio-Emitter consists of a porous cup (Plate 4.5) used in the tensiometer and a unit above that which helps in watering the plants and also in filling the sensor whenever needed. The whole arrangement is simple with least operating parts.

Different designs were conceived and tried for the development of the Tensio-Emitter mechanism. Initially, the porous cup was coupled to a plastic pipe with a piston that was made of rubber (Fig.4.5, Plate 4.1). The arrangement was installed in the soil and it was seen that due to the suction in the soil, there is a downward movement of the piston but it could not develop enough pressure to move the piston upwards after the soil was wet. Hence this system could not be adopted as there won't be any cut off of the water supply. The experiment was repeated with a thinner tube with smaller diameter piston but this too experienced the same problem (Fig. 4.6, Plate 4.2). The thickness of the diaphragm was reduced so as to decrease the friction between the piston and the wall of the tube. But the disk like piston would slide from the sides and thus it failed.

The main challenge experienced in the whole experiment was the small magnitude of the differential pressure available for activating the control mechanism. Hence the piston arrangement did not satisfy the present need.

Next attempt was made with a thin (0.3mm) rubber diaphragm (Plate 4.7). In this case it was seen that the diaphragm responded to the soil moisture tension developed in the soil. A depression was created in the diaphragm due to suction whenever the moisture level in the soil fell down. The diaphragm moved up when there was an increase in the moisture content. Hence this mechanism could be effectively used to develop a valve that works in response to the up and down movement of the diaphragm. The deflection of the rubber diaphragm corresponding to the tension at MAD was obtained from the tension-deflection curve of the rubber diaphragm.

Different valve mechanisms were tried with the diaphragm as the main moving part. A spherical plastic object was used as the valve. The end of the plastic tube was attached with a washer that had a round hole with diameter correctly matching the used sphere (Fig. 4.7, Plate 4.3). In this mechanism it was observed that proper placing of the object to perfectly cover the opening of the tube was not possible. Often the object moved around above the diaphragm which hindered the proper opening and closure or the outlet. Hence this too did not prove to be an appropriate opening and closing mechanism that was desired.

The spherical element was replaced by a conical element and the opening was also given an inclination so that both parts exactly fit into one another (Fig. 4.8, Plate 4.4). This arrangement was seen to be properly responding to the change in moisture content of the root zone. The main operating part being the conical element the dimensions of the Tensio-Emitter controlling mechanism was fixed considering the tension-deflection values (Table 4.11). The deflection of the diaphragm at various pressures was found out by installing a tensiometer and the porous cup with the diaphragm wrapped over that in the same depth into the soil. When the soil started drying the readings in the tensiometer were noted and simultaneous depression in the diaphragm was also noted by sticking a graduated paper over the diaphragm. This procedure was repeated three times and the average values of deflection were obtained. The deflection found was considered in the design of the displacement length of the conical element. The height of the diaphragm was designed according to the depression obtained in the diaphragm at management allowed deficit.

Thus the idea of development of an emitter that worked without an external power supply was achieved. The Tensio-Emitter was then moulded in poly propylene and had four parts: a bottom element which has to be attached to the porous cup, a rubber diaphragm fixed over the bottom element, a conical element connected to the top of the rubber diaphragm that acts as a valve to open or close the water supply and a top element that connects between the water supply and the emitter (Plate 4.11).

3.4 Method

The porous cup is first soaked in water for half an hour so that it becomes completely saturated. Then the moulded bottom part is first attached firmly to the porous cup and then it is filled with deaerated boiled water. The diaphragm is stretched and wrapped over the top of the porous cup. Then the conical head is placed over it and then the top part is correctly attached to it. The water supply line is then inserted into the opening of the top part. The whole assembly should be air tight for the proper working of the emitter.

The emitter was inserted into the soil with the porous cup completely covered with soil in the root zone of the plant and only the watering assembly exposed outside. For refilling the water in the tube in the event of no water supply and soil getting too much dry, an opening is provided in the bottom part of watering assembly. This will help in filling the porous cup without disturbing the whole assembly that prevents the need of calibrating it again. The conical element was attached with a linear extension. Further adjustment of the length of displacement is possible in case of change in MAD by using the linear attachment to the conical element which permits the adjustment of the length of displacement. This allows it to be used in any plant with any water requirement. The performance evaluation was done by plotting a time deflection relationship of the emitter. For this two emitters were installed close to one another in a pot with dry soil mix and the deflection occurring was noted. As the deflection increased the valve opened and dripping started from the emitter thereby decreasing the deflection and finally stopping the irrigation. Further evaluation could not be carried out due to time constraint and also due to cost constraint of material involved in the development of prototype only single unit could be developed. However evaluation of the emitter can be carried out as a further research.

Results & Discussion

Chapter IV

RESULTS AND DISCUSSION

The present study was undertaken with the objective of developing a Tensio-Emitter that automatically controls irrigation based on the matric potential developed in the crop root zone. Its working was based on the tension caused due to the fluctuations in soil water content to initiate and terminate irrigation. Different trials were conducted to find out an apt mechanism that can be adopted for the development of the Tensio-Emitter. Fabrication details and the results obtained in various laboratory experiments are discussed in this chapter.

4.1 State of art of automated irrigation control

Automated irrigation is a much talked about topic in the present day as it has become extremely necessary for a system that is efficient in terms of water use and also labour requirement. Many types of automated systems are available today but are mainly used in large farms for economic crops. The systems are complicated and require external power supply for operation. Thus it becomes economic only in large farms. Many researches are being carried out in order to develop simple mechanisms that can be equally adopted by large scale as well as small gardens at the same time. One such development was that of an irrigation control valve (Peterson *et al*, 1993). The main advantage was that it worked according to the variations in matric potential of the soil, i.e., it does not require an external power for its operation. It could not be freely adopted owing to the complexity of the patented design. Similar work was also carried out as a project work in KCAET in which had a micro tube and metallic triangular head worked as a valve (Sameera *et al,* 2007). The design also had difficulty in cut off as the system cannot generate enough pressure to completely suppress the micro tube. Hence this work is aimed at the development of a simpler mechanism that works on the basis of soil matric potential alone that can be widely adopted and easily installed.

4.2 Characteristics of soil used

For the design of the emitter the various characteristics of the soil has to be known in which the Tensio-Emitter is to be installed. The various characteristics of the soil used for the entire study was tabulated:

Table 4.1 Soil properties

Sl. No.	Soil property		values
1	Bulk density of the mixture using core cutter method		00.86g/cc
2	Texture of the soil	Sand	74.00 %
		Silt	20.00 %
		Clay	06.00 %
3	Field capacity (0.33bar)		16.54%
4	Permanent wilting point (15 bar)		02.12%

4.2.1 Texture of the soil

The texture of the soil was found to be sandy loam from the textural classification chart proposed by U S Public Road Administration.

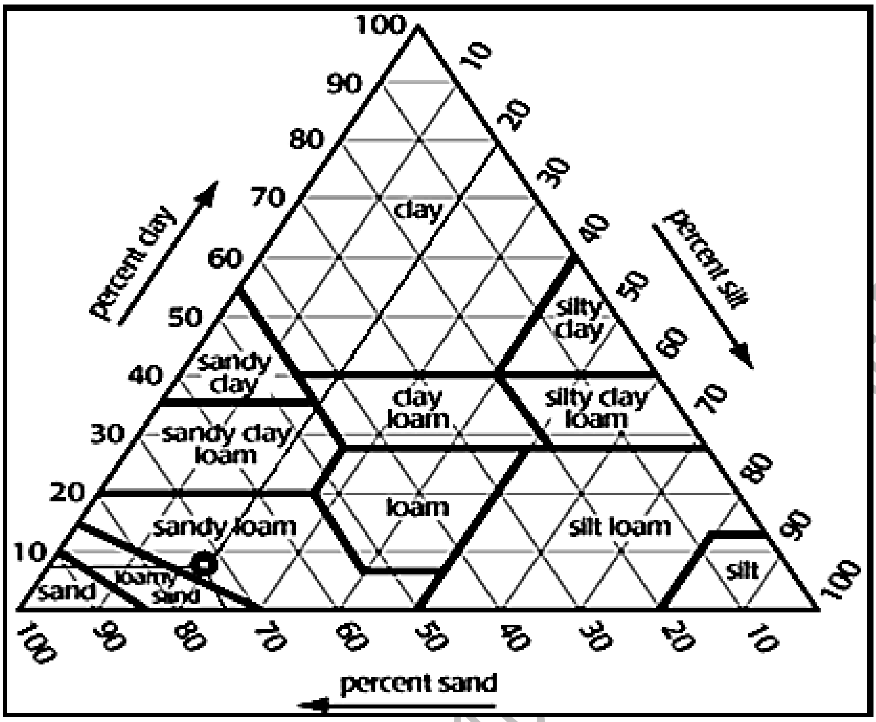

Fig. 4.1 Textural classification chart

4.2.2 Soil moisture characteristic curve

The soil moisture characteristic curve for the drying cycle was plotted with the values obtained from the pressure plate apparatus. For further extending the values curve fitting was done with the help of RETC using the van Genuchten-Mualem equations. The observed and the fitted curves are given in the Fig. 4.2. It can be seen that the curves perfectly fits with that obtained experimentally. Hence this curve can be used effectively.

The actual observed values are given in Table 4.2. The initial values used for the curve fitting in RETC are given in Table 4.3. The correlation matrix for the data fitted to van Genuchten-Mualem equation is given in Table 4.4. It was seen that the four factors are negatively correlated to each other, i.e., increases with decrease in the other value.

Table 4.2 Observed data for the drying curve

Obs. No.	Pressure head(kPa)	Water content (%)
1	33	16.5
2	100	08.0
3	200	06.8
4	1000	06.5
5	1200	05.2
6	1500	02.1

Table 4.3Initial values for curve fitting

No	Name	Initial value
1	θ_r	0.041
2	θ_s	0.065
3	α	0.075
4	n	1.890
5	m	0.428
6	l	0.500

Table 4.4 Correlation matrix

	θ_r	θ_s	α	n
	1	2	3	4
1	1.0000			
2	-.9192	1.0000		
3	-.9194	1.0000	1.0000	
4	.9678	-0.9815	-0.9816	1.0000

Table 4.5 Non-linear sum of squares at 95% confidence level

Variable	Value	S.E.Coeff.	T-Value	Lower	Upper
θ_r	0.0393	0.0586	0.67	-0.213	0.291
θ_s	2.3453	10436.9087	0.00	-44906.632	44911.323
α	0.1951	1187.9288	0.00	-5111.344	5111.734
n	1.7432	2.9258	0.60	-10.846	14.332

From Table 4.5 it can be seen that the observed value and the table value comes in between the lower and upper confidence limits. This shows that the result is significant at 5% level of significance.

For example the observed value for θ_r is 0.039±0.0587. By statistical analysis at 5% level of significance, the table value is 0.67. Thus both come in between the lower and upper confidence limits which show that the result is significant at 5% level of significance.

The coefficient of determination (R^2) value of 0.896 gives good fit. Hence these values can be effectively used for further studies.

Table 4.6 Observed values of drying curve

h (kPa)	S_e	θ (%)
0.00	1.000	41.00
0.10	0.996	40.88
0.12	0.995	40.83
0.14	0.993	40.76
0.17	0.990	40.66
0.20	0.986	40.53
0.24	0.981	40.34
0.29	0.973	40.08
0.35	0.963	39.72
0.42	0.949	39.24
0.51	0.930	38.59
0.61	0.906	37.74
0.73	0.874	36.65
0.87	0.835	35.30
1.05	0.788	33.68
1.26	0.734	31.81

h (kPa)	**S_e**	**θ (%)**
1.51	0.674	29.74
1.81	0.610	27.55
2.17	0.546	25.33
2.61	0.483	23.16
3.13	0.423	21.09
3.76	0.368	19.19
4.51	0.318	17.47
5.41	0.274	15.94
6.49	0.235	14.60
7.79	0.201	13.43
9.35	0.172	12.42
11.22	0.146	11.55
13.46	0.125	10.80
16.15	0.106	10.16
19.39	0.090	9.62
23.26	0.077	9.15
27.92	0.065	8.76
33.50	0.056	8.42
40.20	0.047	8.13
48.24	0.040	7.89
57.89	0.034	7.68
69.46	0.029	7.50
83.36	0.025	7.35
100.03	0.021	7.23
120.03	0.018	7.12
144.04	0.015	7.02
172.85	0.013	6.95

h (kPa)	S_e	θ (%)
207.41	0.011	6.88
248.90	0.009	6.82
298.68	0.008	6.77
358.41	0.007	6.73
430.09	0.006	6.70
516.11	0.005	6.67
619.34	0.004	6.64
743.20	0.004	6.62
891.84	0.003	6.60
1070.21	0.003	6.59
1284.25	0.002	6.57
1541.10	0.002	6.56
1284.25	0.002	6.55
1541.10	0.001	6.55

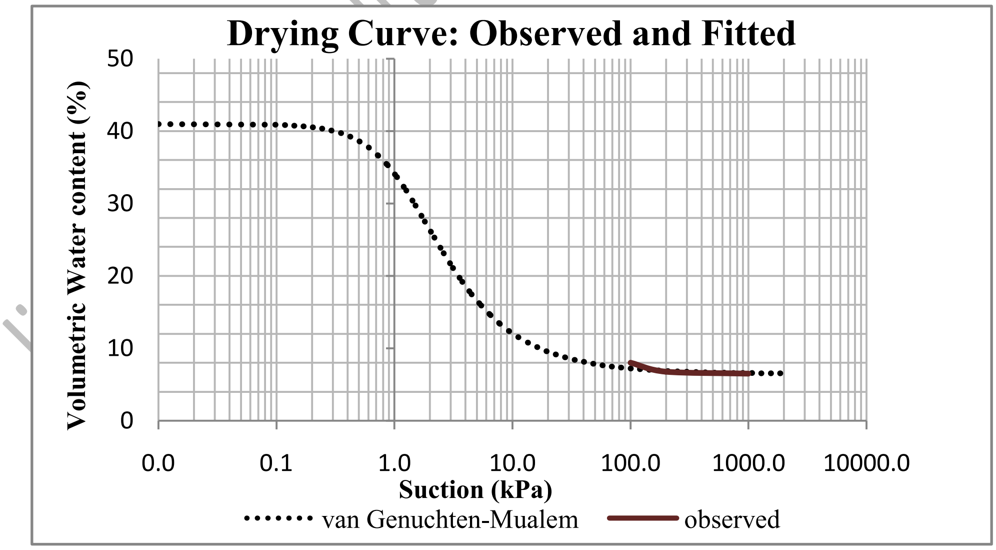

Fig. 4.2 Observed and fitted curve for drying soil moisture characteristic curve

4.2.3 Wetting soil moisture characteristic curve

The wetting soil moisture curve was generated from the values obtained from the capillary tube experiment. This data was fitted to the van Genuchten-Mualem equation using RETC, taking the same initial values for the constants as that of the first case (Table 4.3). The actual observed values are given in Table 4.7. The correlation matrix for fitting this data to van Genuchten-Mualem equation is given in Table 4.8. It was seen that four factors are negatively correlated to each other, i.e., increases with decrease in the other value.

Table 4.7 Observed values of wetting curve

Obs. No.	Pressure head (kPa)	Moisture content (%)
1	00.98	23.21
2	01.96	17.95
3	02.94	12.35
4	03.92	09.62
5	04.9	06.17
6	05.88	04.07
7	06.86	02.97
8	07.84	02.73
9	08.82	02.26
10	09.80	01.96
11	29.40	01.82

Table 4.8 Correlation matrix for wetting Cycle

	θ_r	θ_s	α	n
	1	2	3	4
1	1.0000			
2	-0.3525	1.0000		
3	-0.3107	0.8227	1.0000	
4	0.7888	-0.6004	-0.7308	1.0000

Table 4.9 Non-linear sum of squares at 95% confidence level

Variable	Value	S.E.Coeff.	T-Value	Lower	Upper
θ_r	0.00929	0.00578	1.61	-0.0044	0.0230
θ_s	0.23808	0.00872	27.30	0.2175	0.2587
α	0.03884	0.00256	15.19	0.0328	0.0449
n	3.09926	0.27656	11.21	2.4453	3.7532

The values indicated a non-linear sum of squares at 95% confidence level. The coefficient of determination (R^2) value was 0.99 which indicated a good fit. Hence these values can be effectively used for further studies.

Table 4.10 Observed and fitted values for the wetting curve

$\|h\|$ (kPa)	S_e	θ (%)
0.00	1.000	41.00
0.10	1.000	40.99
0.12	1.000	40.99
0.14	0.999	40.98
0.17	0.999	40.96
0.20	0.998	40.92
0.24	0.996	40.87
0.29	0.993	40.77
0.35	0.988	40.60
0.42	0.980	40.30
0.51	0.965	39.80
0.61	0.941	38.97
0.73	0.902	37.62
0.87	0.842	35.56
1.05	0.758	32.65
1.26	0.651	28.94

h (kPa)	S_e	θ (%)
1.81	0.530	24.78
2.17	0.411	20.66
2.61	0.305	17.03
3.13	0.220	14.09
3.76	0.155	11.86
4.51	0.108	10.24
5.41	0.075	9.09
7.02	0.052	8.28
7.79	0.035	7.72
9.35	0.024	7.34
11.22	0.017	7.07
13.46	0.011	6.89
16.15	0.008	6.77
19.39	0.005	6.68
23.26	0.004	6.63
27.92	0.003	6.59
33.50	0.002	6.56
40.20	0.001	6.54
48.24	0.001	6.53
57.89	0.001	6.52
69.46	0.000	6.51
83.36	0.000	6.51
100.03	0.000	6.51
120.03	0.000	6.50
144.04	0.000	6.50
172.85	0.000	6.50
207.41	0.000	6.50

h (kPa)	S_e	θ (%)
248.90	0.000	6.50
298.68	0.000	6.50
358.41	0.000	6.50
430.09	0.000	6.50
516.11	0.000	6.50
619.34	0.000	6.50
743.20	0.000	6.50
891.84	0.000	6.50
1070.21	0.000	6.50
1284.25	0.000	6.50
1541.10	0.000	6.50
1849.33	0.000	6.50

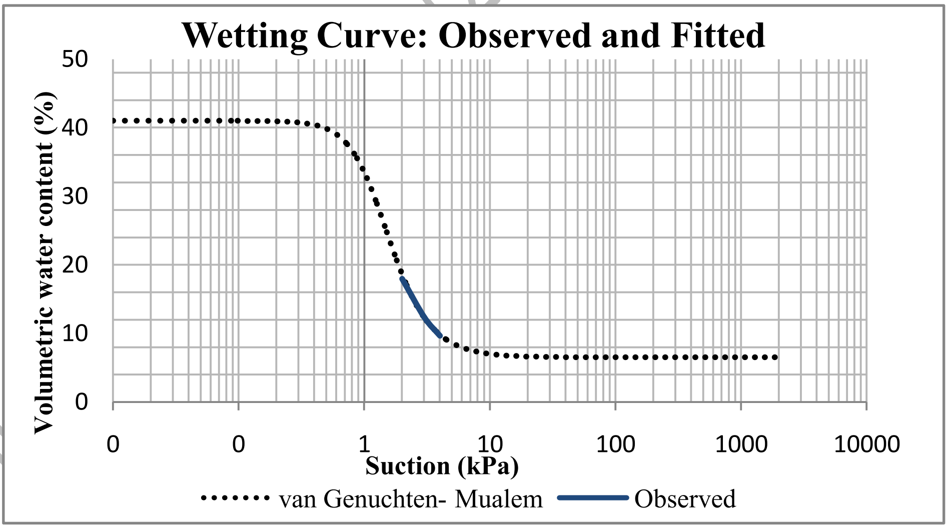

Fig. 4.3 Soil moisture wetting curve (Observed and Fitted)

The soil moisture characteristic curve for the wetting cycle was plotted in 4.3. It shows both observed and the curve obtained from Genuchten-Mualem equations and both show a good fit.

4.2.4 Hysteresis effect in soil moisture characteristic curve

The hysteresis of the soil moisture characteristic curve can be observed when the drying and wetting soil moisture curves are plotted in the same graph. Fig. 4.4 shows the hysteresis effect of the soil moisture characteristic curve.

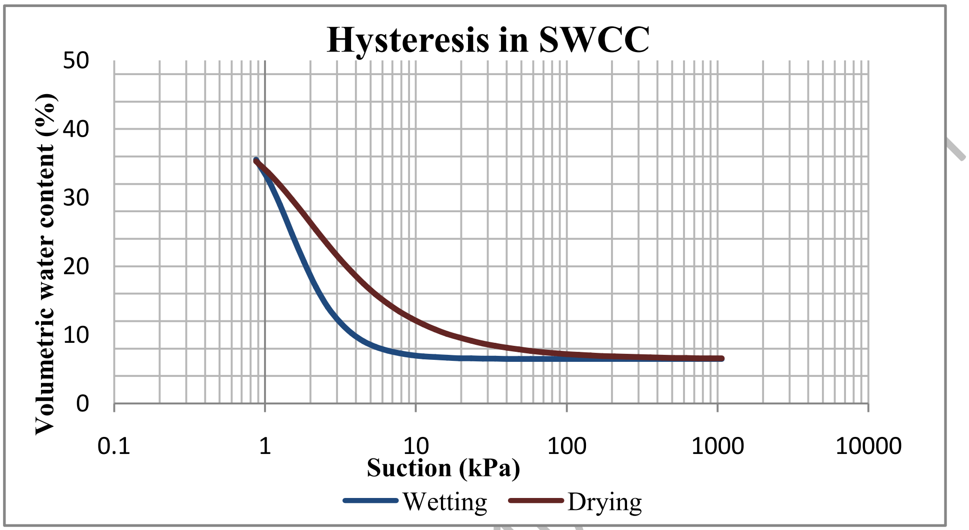

Fig. 4.4 Hysteresis effect in soil moisture characteristic curves.

4.3 Mechanisms for Tensio-Emitter

Different mechanisms were coupled with the porous cup in order to find out the apt mechanism for the proposed Tensio-Emitter.The main aim was to select the best suited mechanism. It was seen that the rubber diaphragm coupled with the porous cup was very responsive according to the soil moisture content. Hence the membrane coupled mechanism was used for the further development of the Tensio-Emitter. The following figues and plates demonstrate the different mechanisms that were tested to be used in the development of the Tensio-Emitter.

Plate 4.1 Mechanism with tube and piston

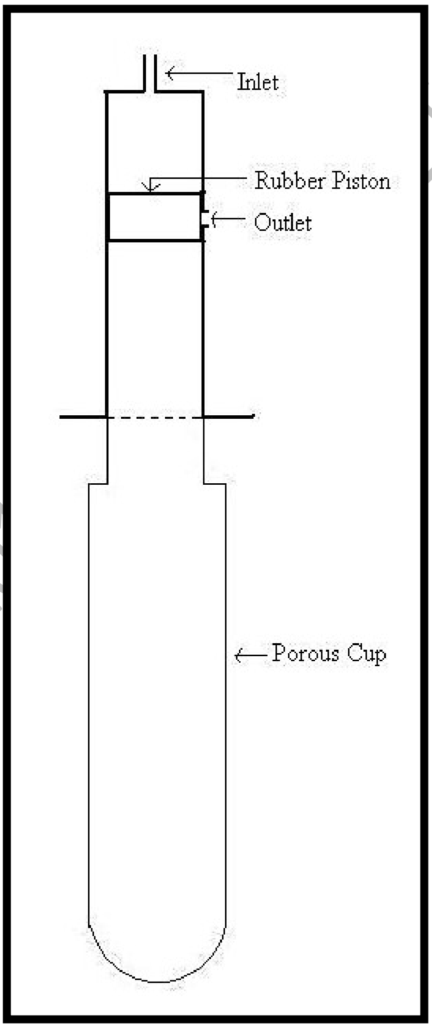

Fig 4.5 Mechanism with tube and piston

Plate 4.2 Thinner tube attachment

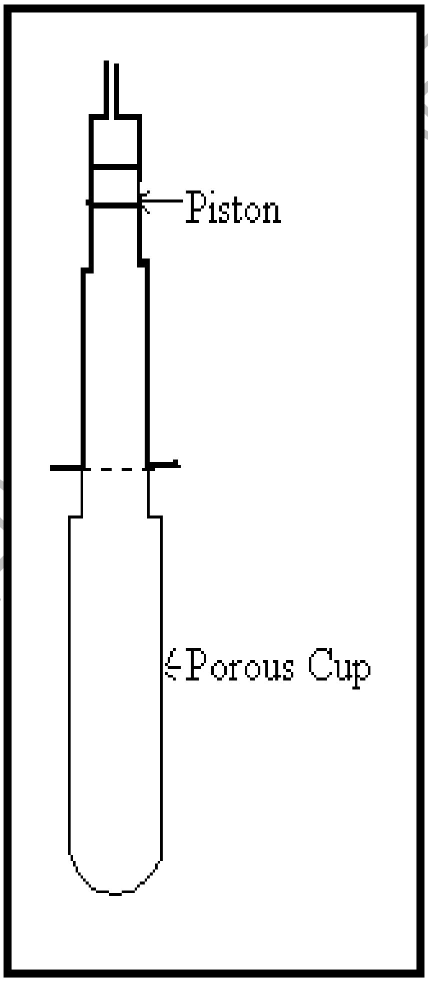

Fig. 4.6 Thinner tube attachment

Plate 4.3 Round object on the diaphragm

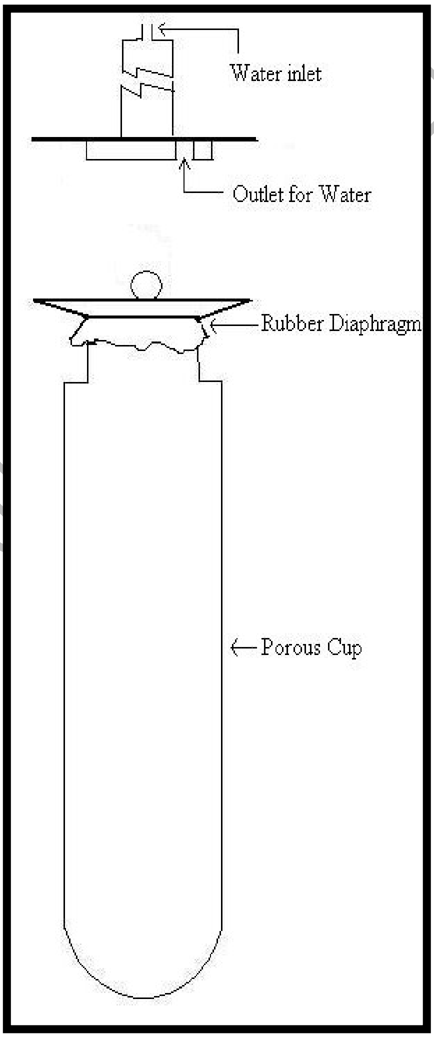

Fig. 4.7 Round object on the diaphragm

Plate 4.4 Conical object on the diaphragm

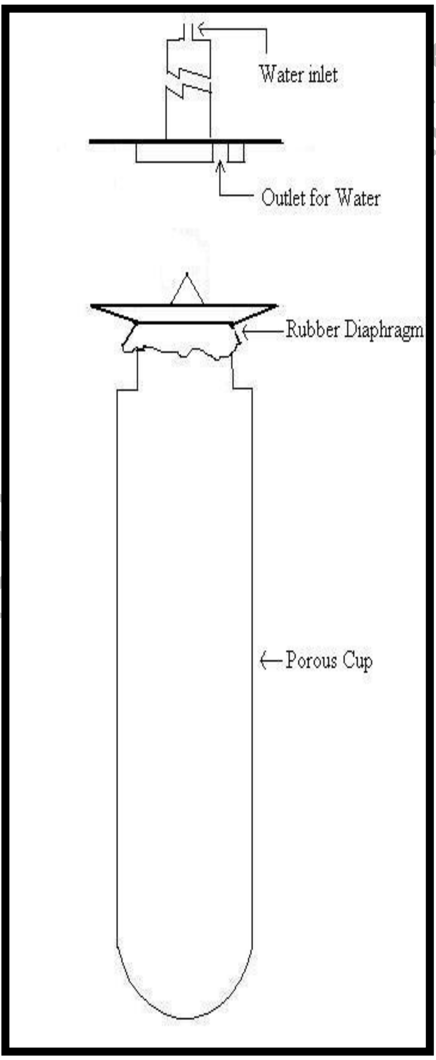

Fig. 4.8 conical object on the diaphragm

4.4 Development of the Tensio-Emitter

It was seen that the mechanism tried using the conical object fixed on the diaphragm worked well. It opened the inlet whenever the water content of the soil deteriorated and could properly close the inlet when the soil was wet. Thus this mechanism was further improved to develop the Tensio-Emitter.

Table 4.11 Deflection experienced by the diaphragm at different pressure

Pressure (kPa)	1	2	3	4	5	6	8	10	12	14	16	18	20
Deflection (mm)	0	0	0.5	1	1	2	2	3	3.5	4	4	5	5

From pressure plate experiment,

Moisture content at field capacity (F.C) = 16.54%

Moisture content at wilting point (W.P) = 2.12%

Available water capacity (A.W.C.) is the portion of water in the soil that can be readily absorbed by the plant roots. It is the amount of water between field capacity and permanent wilting point usually measured in either percentage, in/ft, in/in, mm/mm or m/m.

Available water capacity (A.W.C) = F.C - W.P

= 16.54 - 2.12

= 14.42%

Management Allowed Depletion, maximum allowable depletion, manageable allowable deficiency, allowable soil depletion or allowable soil water depletion is the portion of water that is allowed for plant use prior to irrigation based on plant and its management conditions. Usually it is taken as a percentage of available water capacity expressed as a percentage or decimal.

Management allowable depletion (MAD) = 0.5 * (F.C- W.P)

= 0.5 * 14.42

= 7.21%

Pressure corresponding to MAD = 9 kPa (from SWCC)

Deflection in rubber diaphragm corresponding to the pressure at MAD (Table 11) = 2.5 mm

Thus the design is to be such that when the diaphragm gets deflected 2.5 mm downwards the irrigation has to be triggered. Hence the main working part, i.e., the conical element is designed in accordance with this dimension.

4.5 Components of the Tensio-Emitter

As in any automated irrigation system this tensio- emitter also has sensor as its prime component along with a watering assembly attached to the sensor. The details of each component are given below.

4.5.1 Sensor

The sensor plays a vital role in any of the automated irrigation systems. It is the component which actually informs the controller when to start the irrigation and when to stop it. The sensor used in this study is the tensiometer porous cup (Plate 4.5). The porous cup is one of the important parts of the Tensio-Emitter system and hence its filling is of paramount importance. Before filling the sensor it is advisable to keep it in water for some time, preferably for an hour. This allows the ceramic material enough time to absorb water fully and reduce the pressure built up during the process of sealing. The physical properties of the porous cup are as follows:

Air entry value	:	1.5 kPa
Pore size	:	2 µm
Weight	:	30 g

4.5.2 Bottom part of the emitter

This part was firmly attached to the porous cup so that the other parts can be correctly mounted over this (Fig. 4.10, Plate 4.6). An opening is also provided for this so as to fill water into the porous cup whenever it gets depleted. Other times it has to be tightly closed so that no air enters into the cup during operation.

Another extension was given at the opposite side of the opening in order to tie up both the parts in case they tend to move apart due to elasticity of the diaphragm.

4.5.3 The diaphragm

A thin diaphragm was preferred for proper working of the emitter. Hence a rubber diaphragm was used for this purpose (Plate 4.7). It is easily available and performs the work accurately.The thickness of the diaphragm was measured to be 0.3 mm. It also had property that it can be stretched up to seven times its original dimension and still it comes back to original shape.

4.5.4 Conical component

The conical part that was placed in between the top and bottom part of the emitter acts as a valve that opens and closes the water inlet passage (Plate. 4.8). This is simply placed on the diaphragm and is positioned to fit into the inlet of the top part. Since the diaphragm had a movement of 2.5mm at the required pressure, the height of the conical part was designed accordingly. The distance between the opening of the upper part and the diaphragm was given as 5 mm and the cone will get seated inside the opening and this makes another 3mm. Thus the total length of the cone was given as 8mm (Fig.4.9). the valve completely opens only when the diaphragm moves more than 2.5mm downwards.

A hole was provided at the top end of the conical part so as to insert a thin rod to place it properly in position. The length of the rod can be adjusted so that the opening of the emitter can be adjusted for future development when the emitter is used for other textured soil.

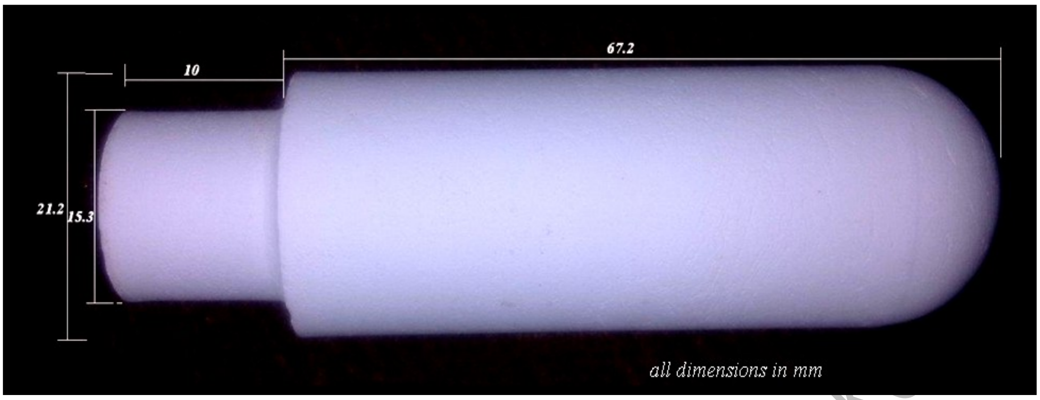

Plate 4.5 Tensiometer porous cup used as sensor

Plate 4.6 Bottom part of the emitter

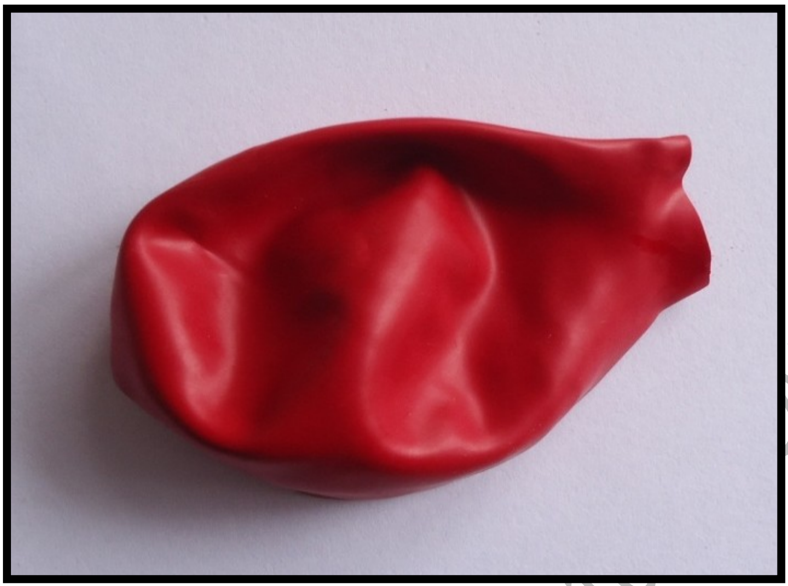

Plate 4.7 Diaphragm

Plate 4.8 Conical component

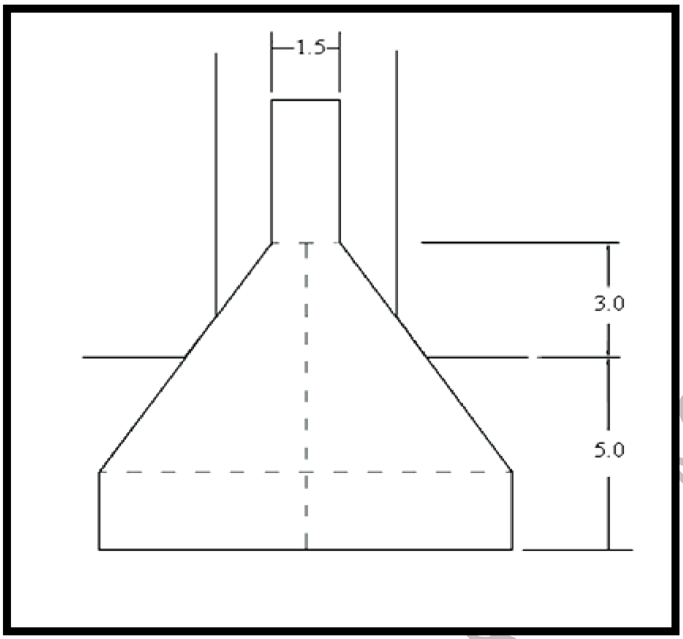

Fig. 4.9 Line diagram for the conical element

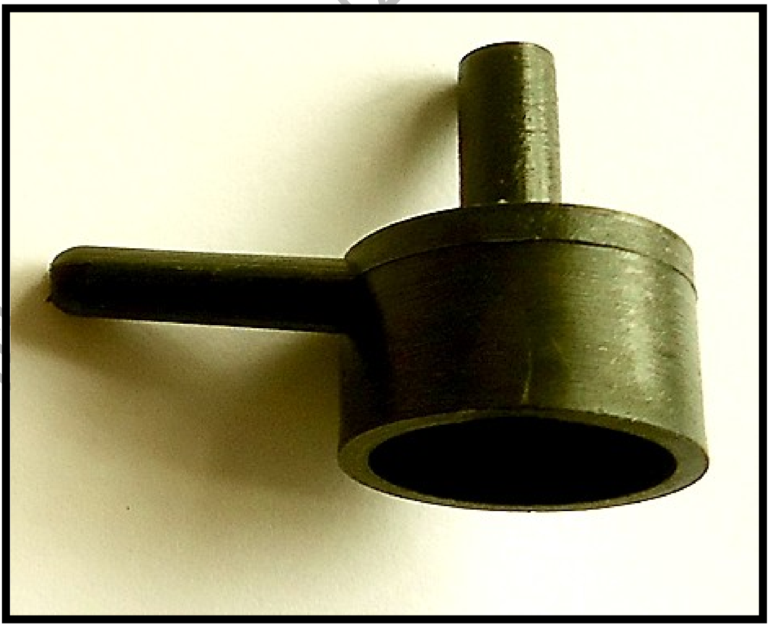

Plate 4.9 Upper part of the emitter

4.5.5 Upper part of the emitter

The moulded upper part consisted of two openings, one for the water supply inlet and the other is the outlet for irrigation water. Water supply line is connected to the top portion and the passage is blocked by the conical object. As the soil dries the passage opens and water flows through the emitter to the outlet (Fig.4.11, Plate 4.9)

4.6 Assembling and installation of the Tensio-Emitter parts

The various components of the Tensio-Emitter are to be assembled as shown in Plate 4.10 and Fig. 4.12. After filling the porous cup with water and assembling the emitter, it is to be inserted into the soil in the root zone of the plant. The sensor, i.e., the porous cup has to be completely inserted into the soil. As the moisture content of the root zone gets depleted, the water from the porous cup is drawn by the soil. Being an airtight system there is a tension build up in the porous cup which causes deflection of the diaphragm inwards. This causes the conical part also to move down thereby opening the passage of water initiating irrigation. As and when the soil gets wet again the tension experienced by the porous cup reduces eventually causing the diaphragm to move to its original position. This again blocks he passage of water thus stops the irrigation.

Plate 4.10 Assembled view of Tensio-Emitter

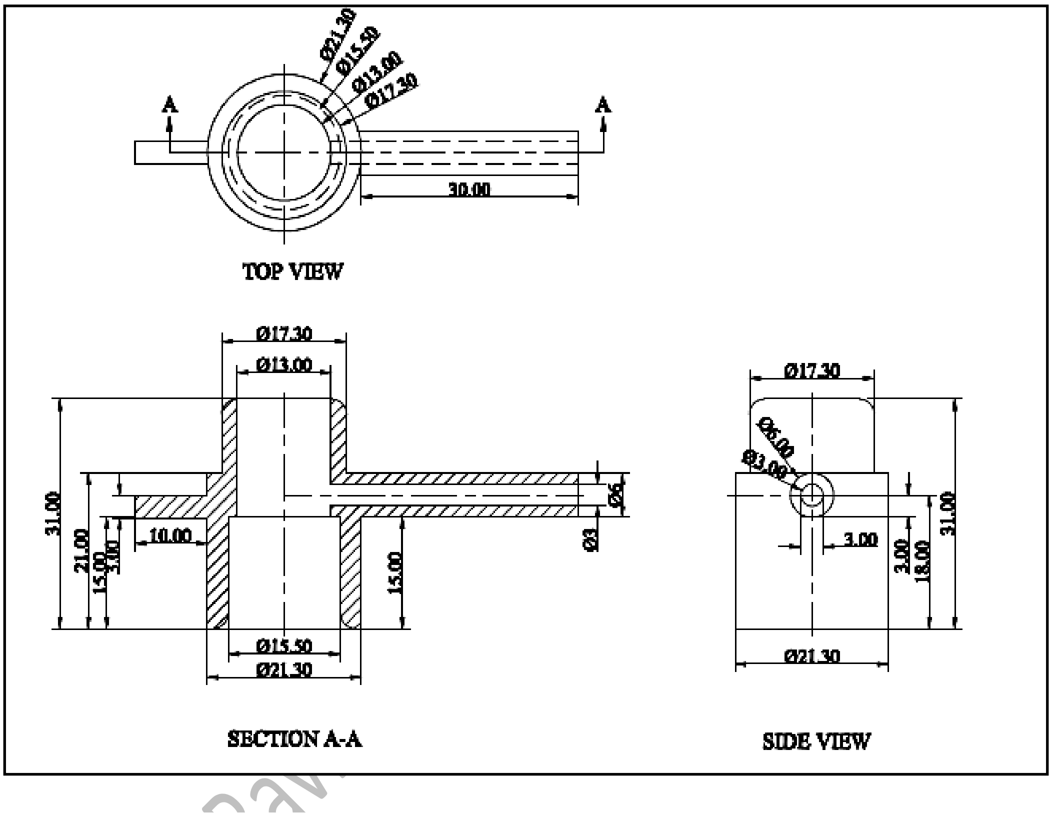

Fig. 4.10 Orthographic view of the bottom part of tensio-emitter

All dimensions in mm

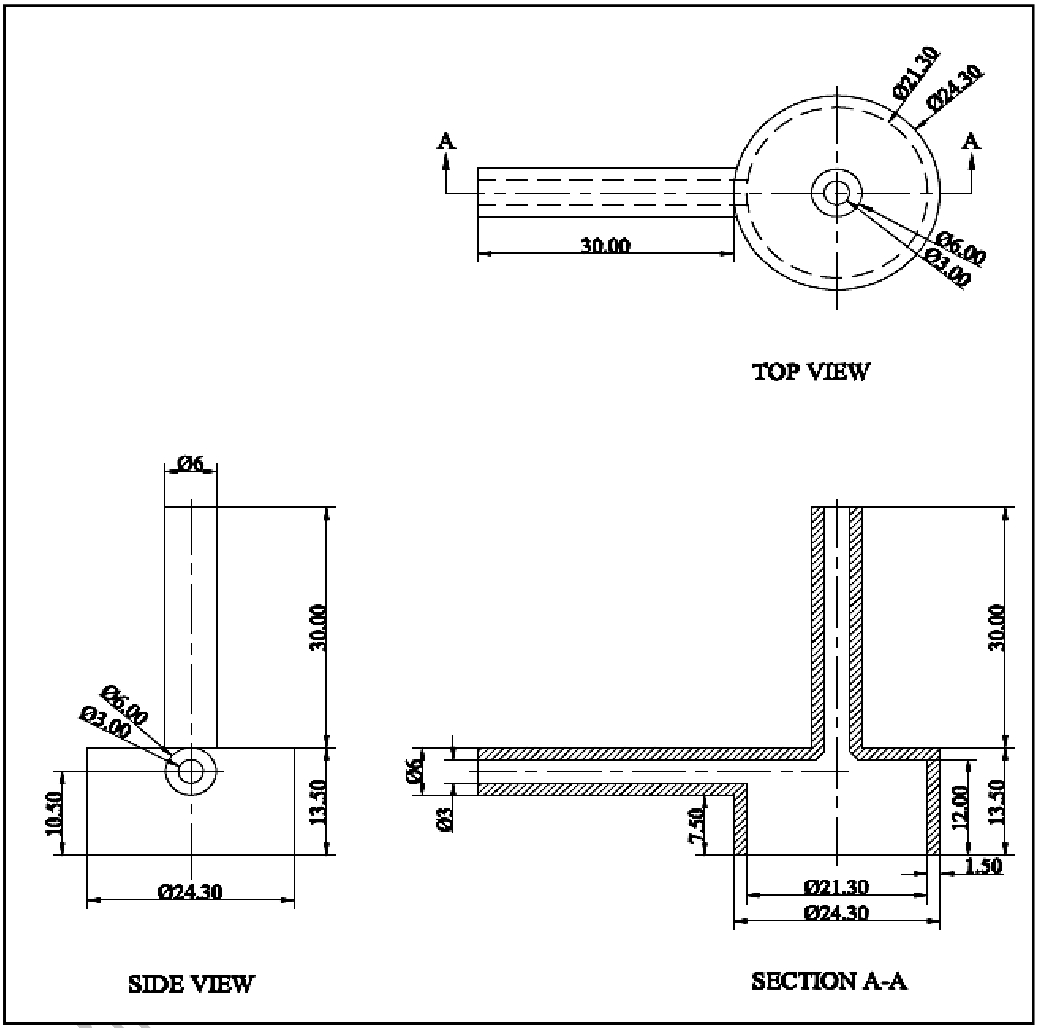

Fig. 4.11 Orthographic view of the top part of tensio-emitter

All dimensions in mm

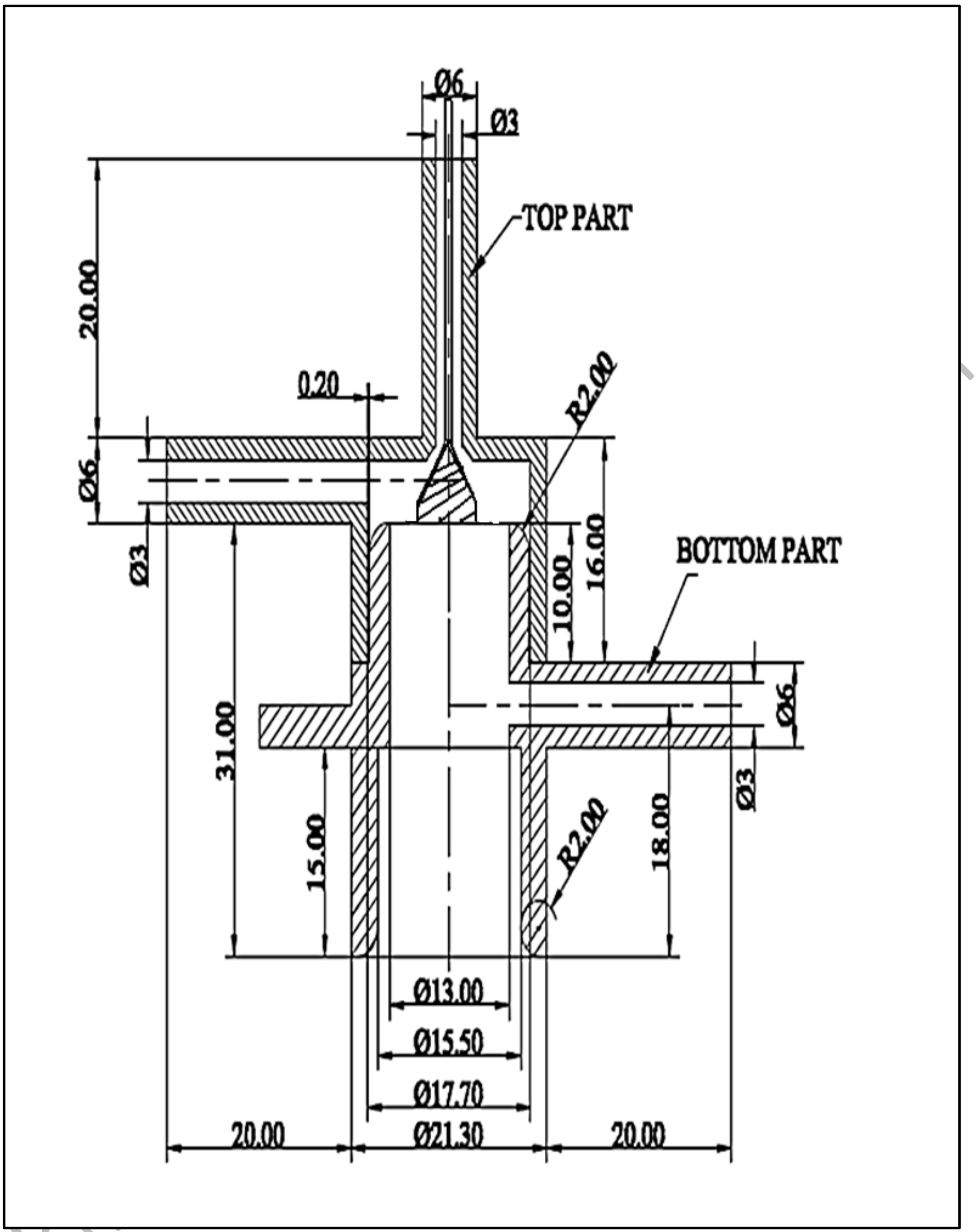

Fig. 4.12 Assembled view of tensio- emitter

All dimensions in mm

4.7 Adjustment of the Tensio-Emitter

Before using the system it has to be checked for water tightness as well as air tightness. Then turn on water to the drip hose. For the purpose of running test, loosen the upper part of the Tensio-Emitter till a strong stream of water flows out of the drip tube. Drip distance is another important factor. The distance from the drip location to the root zone influences the water application in by the emitter. Hence the drip outlet should be such that the water drops falls above the root zone.

4.7.1 Standard adjustments

Slowly close the upper part of the emitter until just a single drop of water remains hanging on the end of the drip tube. This "zero adjustment" ensures that the sensor shuts off automatically when enough moisture is available (i.e. after rain or irrigation). The zero adjustment should be done after the sensor adapts to the soil moisture. This takes about 3- 4 h after insertion into the wet earth.

4.7.2 Calibrations and correction

Adjust the sensor on the following days for about a week. Dripping should start when the earth surface is dry; otherwise, loosen the upper part a little. If the earth remains wet, then drips should not be seen even gradually emerging from tube; in this case, press the upper part a little more. Proper adjustment requires a certain degree of delicate touch.

When a more intensive watering is desired for specific plants, increase the distance between the drip end and sensor by attaching a tube at the end of the outlet to 10-15 cm, thereby increasing the duration of watering (the water has a longer way to reach the sensor). If the distance is more than 8 cm, for potted plants the extra water may drip out of the pot.

4.8 Evaluation of the working of the Tensio-Emitter

The developed Tensio-Emitter's performace with respect to its ability to automatically control the irrigation according to the soil moisture level was studied. The Tensio-Emitter was installed in the pot (Plate 4.11). It was seen that the emitter worked properly and the valve opened whenever the soil moisture suction was below the tension at MAD. Once the soil is wet enough (i.e. when it reaches field capacity) the valve closed to stop the flow of water. When the soil moisture tension increases, the valve opens and water starts to drip and when the tension increases to that corresponding to the MAD, the valve fully opens. As the soil receive water, the soil moisture tension decreases, slowly closing the valve and thus decreasing the flow and finally the water flow stops completely at the field capacity. Thus the developed Tensio-Emitter was found to be able to work as an irrigation controller within the designed soil moisture tension ranges. Further performance evaluation of the emitter with respect to its discharge rate at different pressures etc. is beyond the scope of this study and that may be taken up as a future work.

4.9 Cost of fabrication of the Tensio-Emitter

The total cost involved in the fabrication of a single unit of the Tensio-Emitter are given below:

Cost of the porous cup used as the sensor	= ₹ 750
Cost of fabricating the mould of the bottom element of the emitter	= ₹ 3000
Cost of fabricating top part mould of the emitter	= ₹ 3000
Cost of fabricating conical element mould	= ₹ 500
Cost of rubber diaphragm	= ₹ 1
Total	= ₹ 7252

Cost estimation of the developed Tensio-Emitter

Cost of the porous cup used as the sensor = ₹ 750

Cost of the moulded assembly = ₹ 5

Cost of rubber diaphragm = ₹ 1

Total cost = ₹ 756

Hence the total cost for one emitter cames to around ₹ 756. The high cost of the Tensio-Emitter was due to the imported porous cup, which if substituted with a locally manufactured one can reduce the cost as the other items costs only ₹ 6.

It is feasible to substitute the porous cup with indegenously manufactured ones having very less cost as the water filter candles made of similar material is selling at ₹ 30 only.

Plate 4.11 Working of the Tensio-Emitter

4.10 Scope for improvements and future developments:

The developed Tensio-Emitter that worked on soil matric potential functions very well, however, there experienced some inconveniences to its use at present.

- The Tensio-Emitter has to be calibrated after installing in the root zone.
- The life of the diaphragm used in the proto-type is less. However, when manufactured, long lasting diaphragm can be used.

Suggestions for improvements and future modifications:

- Local manufacturing of the porous cup reduces its cost
- Mass production reduces cost and permit its adoption in the field.

Summary & Conclusions

SUMMARY AND CONCLUSION

Irrigation is the major user of water and the increasing scarcity of water demands use of water conserving irrigation systems that utilizes accurate amount of water only. The pressurized irrigation satisfies this condition. But modern automated irrigation techniques are complicated and are widely adopted in large farms. Hence this study is aimed to the development of simple emitter that works without an external power supply. This kind of an emitter can be effectively utilized in small kitchen gardens and potted plants. A Tensio-Emitter was developed which works based on the soil matric potential in the plant root zone. The soil characteristic of the potting mixture was studied and the soil moisture characteristic was plotted for both drying and wetting cycle, thus producing the SWCC. The water available for the plants in the range between the field capacity and the permanent wilting point for the selected soil was found. A tensiometer porous cup was used as the sensor. The porous cup was attached to a cylindrical stem containing a valve assembly in which a rubber diaphragm coupled with a conical element was used for controlling the water flow. The conical element was kept over the diaphragm and the up and down movement of this conical element along with the diaphragm resulted in the valve action. A tensiometer and the stem with the porous cup and diaphragm were installed in a pot and the depression in the diaphragm at different tension ranges was measured. The dimensions of the assembly were fixed based on the size of the porous cup available and the tension available at MAD. The conical element dimensions were calculated based on this data. The emitter would discharge water whenever the soil moisture level comes down and would stop when the soil is wetted up to field capacity. This enabled the watering of the plants according to the soil moisture tension, thus ensuring automatic irrigation. The unit cost of the controller assembly is estimated at Rs. 6 only but the cost of the porous cup (imported) was about Rs. 750, which can be considerably reduced when large scale local manufacturing is done. The developed Tensio-Emitter can be effectively used for automated irrigation without any external power supply.

References

REFERENCES

Bakker, G., Martine, J., Ploeg, V. D., Gerrit H., Hoogendam, C. W., Hermanus, P. A., Huiskes, C., Koopal,L. K., and Kruidhof, H. 2007. New polymer tensiometers: measuring matric pressures down to the wilting point. *Vadose Zone Journal*: 196-202.

Boman, B., Smith, S. and Tullos, B. 2002. Control of Irrigation in Citrus Micro-irrigation System. Retrieved July 1, 2012, from Institute of Food and Agricultural Sciences, University of Florida: http://edis.ifas.ufl.edu/ch194.

Browne, L. C. 1990. Self-servicing hydraulic tensiometer with electrical switching and response Capabilities. *US Patent Number 4922945.*Issue date: May 8, 1990.

Carpena, M. R., Dukes, M. D., Li, Y. C., and Klassen, W. 2003. Field comparison of tensiometer and granular matrix sensor automatic drip irrigation on tomato.*Hort. Technology (15)*:584-590.

Carpena, M. R. and Dukes, M. D. 2005. Automatic irrigation based on soil moisture for vegetable crops. Retrieved July 7, 2012, from Institute of Food and Agricultural Sciences, University of Florida: http://edis.ifas.ufl.edu/ae354.

Cui, Y. J., Tang, A. M., Mantho, A. T., and Laure, E. D. 2008. Monitoring field soil suction using a miniature tensiometer. *Geotechnical Testing Journal (31)*: 1-15.

Dukes, M. D. 2007. Residential irrigation water use and control in S. W. Trimble, *Encyclopaedia of Water Science*: 965-967.

Dukes, M. D., Shedd, M., and Lailhacar, B. C. 2008. Smart irrigation controllers: how do they work? Retrieved July 7, 2012, from Institute of Food and Agricultural Sciences, University of Florida: http://edis.ifas.ufl.edu/ae437.

Dukes, M. D. 2009. Smart irrigation controllers: what makes them smart? Retrieved June3, 2012, from Institute of Food and Agricultural Sciences, University of Florida: http://edis.ifas.ufl.edu/ae442.

Elmaloglou, S. and Diamantopoulos, E. 2008. Effects of hysteresis on distribution of soil moisture and deep percolation at continuous and pulse drip irrigation. *Pulse (96)*:533-538.

Fredlund, D. G. and Xing, A. 1994. Equations for the soil-water characteristic curve. *Can. Geotech. J. (31)*: 521-532.

Fredlund, M. D., Wilson, G. W., and Fredlund, D. G. 1998. Estimation of hydraulic properties of an unsaturated soil using knowledge based system. *Second international conference on unsaturated soil*, Beijing:pp. 27-30.

Galal, M. E. 2004. Estimating soil hydraulic parameters in El-Tina plain using RETC program. *International Conf. on Water Resources & Arid Environment*, Egypt: pp. 1-5.

Gitirana, F. N., and Fredlund, D.G. 2004. Soil-water characteristic curve equation with independent properties. *Geotechnical and Geo-environmental Engg. J., (130)*: 209-212.

Grover, B. K., Hubbell, J. M., Sisson, J. B., and Casper, W. L. 2004.Tensiometer methods and apparatus. *U S Patent No. 6772621.* Issue date: Aug 10, 2004.

Haman, D. Z and Zazueta, F. S. 1998. Valves in irrigation systems. Retrieved January17, 2012, from Institute of Food and Agricultural Sciences, University of Florida: http://edis.ifas.ufl.edu/wi005.

Huang, H. C., Tan, Y.C., Liu, C.W., Chen, C. H. 2004. A novel hysteresis modeling unsaturated soil. *Hydrological Processes 19(8)*: 1653 – 1665.

Hubbell, J. M., and Sisson, J. B. 2003. Self compensating tensiometers and method. *US Patent No. 6539780.* Issue date: Apr. 1, 2003.

Jones, H. G. 2004. Irrigation scheduling: advantages and pitfalls of plant based methods. *Journal of Experimental Botany*: 2427- 2436.

Looms, M. C. 2003. Investigation of the dynamic effects on unsaturated hydraulic parameters. Denmark: Environment and Resources Technical University.

Lourenco, S. D. N., Gallipoli, D., Toll, D. G., Augarde, C. E., Evans, F. D. and Medero, G. M. 2008.Calibrations of high-tension tensiometer. *Geotechnique*: 659-668.

Luthra, S. K., Kaledhonkar, M. J., Singh, O.P., and Tyagi, N. K. 1997. Design and development of an auto irrigation system. *Agricultural Water Management (33)*: 169- 181.

Majumdar, D. K. 2000. *Irrigation Water Management Principles and Practice.*Prentice Hall of India Pvt. Ltd., New Delhi, 481p.

Migliaccio, K. W. 2007. Sustainability of agriculture in Miami-Dade County: considering water supply. Retrieved July 4, 2011, from EDIS publication system: http://edis.ifas.ufl.edu/ae429.

Nzokou, P., Gooch, N. J., and Cregg, B. M. 2010. Design and implementation of a soil matric potential-based automated irrigation system for drip irrigating Fraser Fir. *Hort. Technology (6)*: 1031-1036.

Or, D. 2001. History of Soil Science: Who invented tensiometer? *Soil Sci. Soc. Am. J. (65)*: 1-3.

Pardossi, A., Incrocci, L., Incrocci, G., Malorgio, F., Battista, P., Bacci, L., Rapi, B., Marzialetti, P., Hemming, J., and Balendonck, J. 2009. Root zone sensors for irrigation management in intensive. *Sensors* : 2809-2835.

Peterson, D. L., Glenn, D. M and Wolford, S. D. 1993. Tensiometer irrigation control valve. *Applied Engineering in Agriculture (9)*: 293-297.

Pham, H. Q., Fredlund, D. G., and Barbour, S. L. 2003. A practical hysteresis model for the soil water characteristic curve for soils with negligible volume change. *Geotechnique (53)*: 293-298.

Ploeg, V. D., Gooren, M. J., Bakker, H. P. A., and Hoogendam, C. W. 2009. Polymer tensiometers with ceramic cones: performance in drying soils and comparison with water-filled tensiometers and time domain reflectometry. *Hydrology and Earth System Sciences (6)*: 4349–4377.

Richards, L. A. 1941. Soil moisture tensiometer materials and construction [on line]. Available: http:// afrsweb.usda.gov/SP2UserFiles/Place/53102000/ pdf_pubs/ P0015.pdf

Richards, L. A. 1962. Gage attachment and air removal arrangement. *U S Patent No. 3043133.*Issue date: Jul 10, 1962.

Sameera, A. S., Della, T. and Anu, S. K. 2007. Development of a Tensio-Emitter. B Tech project report, KCAET, Tavanur.

Smajstrla, A.G., and Harrison, A. G. 1998.Tensiometers for soil moisture measurement and irrigation scheduling. Retrieved July 4, 2011, from EDIS publication system: http://edis.ifas.ufl.edu/ae146.

Smajstrla, A. G., and R. C. Koo. 1986. Use of tensiometers for scheduling of citrus irrigation. *Proceedings of the Florida State Horticultural Society (*99):51-56.

Smajstrla, A. G. and Locascio, S. J. 1990.Irrigation scheduling of drip- irrigated tomato using tensiometer and pan evaporation. *Proc. Fla. State Hort. Soc. (103)*: 88-91.

Skaling, P. E. 1978. Portable tensiometers for soil moisture measurement. *US Patent No. 4068525*. Issue date: Jan 17, 1978.

Tal, A. 1975.Tensiometer and automatic irrigation control system utilizing same. *US Patent No. 3910300.* Issue date: 1975.

Thalheimer, M. 2003. Tensiometer modification for diminishing errors due to the fluctuating inner water column.*Soil Sci. Soc. Am. J. (67)*: 737–739.

Tuller, M. and Or, D. 2003.Retention of water in soil and the soil water characteristic curve. Available:http://www.engr.uconn.edu/environ/envphys/pdf/vadose_pdf/SWC_revised01.pdf.

van Genuchten, M.T., Leij, F.J., Yates, S.R. 1991. The RETC code for quantifying the hydraulic functions of unsaturated soils. Report No. EPA/600/2-91/065, R. S. Kerr Environmental Research Laboratory, U.S. Environmental Protection Agency, Ada, OK, 85pp.

Warrick, A. W.,Wierenga, P. J., Young, M. H., and Musil, S. A. 1998. Diurnal fluctuations of tensiometric readings due to surface temperature changes. *Water Resources Research (34)*, 2863–2869.

Whiting, D., Card, A., and Wilson, C. 2011. Estimating Soil Texture: Sand, Silt or Clayey. In *CMG GardenNotes #21* Retrieved July 25, 2012, from http://www.ext.colostate.edu/mg/gardennotes/214.html

Yang, H., Rahardjo, H., Leong, E. C., Fredlund, D. G. 2004. Factors affecting drying and wetting soil-water characteristic curves of sandy soils. *Can. Geotech. J. (41)*, 908-920.

Yates, S. R., Van Genuchten, M. T., Warrick, A. W., and Leij, F. J. 1992.Analisys of measured, predicted and estimated hydraulic conductivity using RETC computer program. *Journal of American Soil Science Society (56).* 347-354.

Zhou, J and Yu, J. L. 2005. Influences affecting the soil-water characteristic curve. *Zhejiang University. J. (6):*797-804.

Zazueta, F. S., Smajstrla, A. G., and Clark, G. A. 1993.*Irrigation System Controllers.*Retrieved July 7, 2011, from Institute of Food and Agricultural Sciences, University of Florida: http://edis.ifas.ufl.edu/ae077.

Abstract

DESIGN AND DEVELOPMENT OF
TENSIO-EMITTER

by

JISHITHA RAVINDRAN

(2010 – 18 – 104)

ABSTRACT OF THE THESIS

Submitted in partial fulfillment of the

requirement for the degree of

MASTER OF TECHNOLOGY
IN
AGRICULTURAL ENGINEERING

Faculty of Agricultural Engineering & Technology

Kerala Agricultural University

DEPARTMENT OF LAND &WATER RESOURCES AND CONSERVATION ENGINEERING

KELLAPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

TAVANUR - 679573

2012

ABSTRACT

Timely application of precise amounts of irrigation water increases crop yield due to the decreased moisture stress to plants. Automatic application of irrigation water ensures timely and precise water application, reduces labour cost and prevents water loss and nutrient leaching. Automatic irrigation usually involves sophisticated and expensive instrumentation requiring external power. An irrigation control system that utilizes only the moisture tension to directly control the water application, without using any external power source is desirable for its simplicity and usability in remote areas. In this study, an attempt was made to develop a simple and cost effective irrigation controller working on the basis of soil moisture tension without any external power source.

A Tensio-Emitter was developed after evaluating several designs suitable for the same. The developed Tensio-Emitter consists of a porous cup fixed on a stem and an emitter cum valve assembly. The porous cup acts as a sensor which equilibrates the tension inside the stem to that of the surrounding soil. The emitter cum valve assembly consists of a bottom part to be fixed on the stem containing the porous cup, a flexible diaphragm, a conical part to be attached to the diaphragm and a top part which has as the water inlet and outlet. The dimensions of the emitter cum valve assembly was determined based on the size of the available porous cup, the soil moisture tension available at MAD and the deflection of the diaphragm at the tension corresponding to MAD. The Tensio-Emitter is calibrated by adjusting the conical part such that water flow through the emitter starts when the soil becomes dry and stops when the soil reaches field capacity moisture content. Tensio-Emitter – a simple and cost effective irrigation controller cum emitter which is activated by soil moisture tension - was successfully developed, fabricated and calibrated for use in potted plants. The ability of the developed Tensio-Emitter to automatically control the irrigation according to the soil moisture level was evaluated to be good.