EXPERIMENTAL RESEARCH ON MOISTURE TRANSMITTING RATE BETWEEN HUMIDITY SENSITIVE MATERIAL AND THE EXTERNAL ENVIRONMENT
/
水分在湿敏材料与外界环境间传输速率的试验研究

Lect. Ph.D. Chen Zhongjia[1)], Lect. Ph.D. Yuan Xiangyue[*1)], Prof. Ph.D. Eng. Yu Guosheng[1)], Prof. Ph.D. Eng. Grigu Kaunyon [2)]
[1)] School of Technology, Beijing Forestry University, Beijing / China;
[2)] Laboratory for Advanced Agricultural Technology R&D, MOAD Companies Group, Inc., Takatsuki / Japan
Tel: +861062338144; Email: shirley_yxy2001@163.com

Abstract: *Shortage of water resources has become a serious problem of the world. With the growing increasingly reduction of water and energy resources, the agricultural irrigation method of water-saving and energy-saving should be adopted. In developed countries, control and monitoring of agricultural water-saving irrigation products are mostly dependent on computer technology, which need an external power source, and the price of the whole irrigation system is very expensive. So, it is not suitable to remote forest areas in China. In this paper, a new type of water-saving valve was introduced and is characterized by high automation, low costs and is capable of controlling without power supply. In order to make the valve to be used better in agricultural irrigation, experiments on moisture transmission rate between humidity sensitive materials and the external environment were conducted. And the results showed that the control unit of the valve could realize the irrigation automatically and timely according to the transmission rate between humidity sensitive material and the external environment, which would provide theoretical and experimental basis for the accurate control of the valve. It would play an important role for expanding agricultural water-saving irrigation and accelerating the speed of rational use of water resources.*

Keywords: *Water-saving valve; Humidity sensitive material; Transmission rate; Agricultural irrigation; Water Crisis*

摘要: *水资源短缺已经成为全世界面临的严重问题。随着水资源和能源的日益减少，必须发展农业节水节能灌溉技术。在发达国家，农业节水灌溉产品的监控系统大多依赖计算机技术，它需要有外部电源供给，且整个系统的价格非常昂贵，因此不适用于中国的偏远地区。本文介绍了一种新型的节水阀门，它具有高自动化高、低成本且能实现无电源控制的特点。为了使该阀门能更好地应用于农业生产灌溉，本文进行了水分在湿敏材料与外界环境间传输速率的试验研究。试验结果表明，阀门的控制单元能根据湿敏材料和外部环境之间水分传输的速率实现自动和及时的灌溉，这将为阀门的精准控制提供理论和试验依据。对于发展农业节水灌溉和加速水资源的合理利用也能起到重要的作用。*

关键词: *节水阀门; 湿敏材料; 传输速率;农业灌溉; 水资源危机*

INTRODUCTION

Water is the most important limited resources among all the natural resources, thus it should be tapped and utilized rationally. China accounts for only 9% of arable land resources in the world, and even a less percent of 6% of world's water resources. At the same time, half of more than 600 cities in China are deficient in water resources. What's more, the distribution of water resources in China is not even. For example, North China and Northeast account for 40% of national population with only about 5% of national water resources, and the 25% fresh water resources in North China is from South China. At present, the water supply is only 6180 billion cubic meters in China [9], while it is estimated that water demand will amount to 8180 billion cubic meters by 2030. In addition, China is an agricultural country and 40% arable land needs irrigation [10]. Therefore, agricultural water-saving and energy-efficient irrigation has become an irresistible trend to relief the water resource crisis and realize agricultural modernization.

In recent years, agricultural water-saving irrigation equipment in the world still faces many problems in spite of certain development. In China, the automation level of water-saving irrigation equipment especially in remote areas is so poor that they are generally controlled

引言

在所有自然资源中，水是最重要的有限资源，必须合理开发和利用。中国耕地资源占世界总量的 9%，然而，水资源更加紧缺，仅占世界总量的 6%。同时，在中国 600 多个城市中，一半的城市存在水资源匮乏问题。另外，中国的水资源在全国范围内分布不均匀，例如，华北和东北虽然人口占全国人口的 40%，但水资源仅占全国总量的 5%左右，华北的淡水资源仅为华南的 25%，预计到 2030 年，中国的需水量预计达到 8180 亿立方米。目前，供水量仅有 6180 亿立方米[9]。除此之外，中国作为一个农业大国，其中 40%的耕地面积需要通过灌溉来完成生产[10]。因此，采用农业节水、节能的灌溉方法已成为中国灌溉技术发展的总趋势，推广节水灌溉也已成为中国为缓解水资源危机和实现农业现代化的必然选择。

近年来，国内外的农业节水灌溉设备虽有一定的发展，但仍存在不少的问题。国内尤其在偏远地区的节水设备自

manually by installing all kinds of valves. Currently, micro-irrigation equipment is only applied to such cash crops as fruits and vegetables, and still needs development for field crops, while foreign equipment with a high overall level, whose automatic control system are realized mostly by using computers, sensors and remote sensing and telemetry and etc. [7], which means a high cost beyond the reach of most farmers or foresters in China. In the early 1940s, L. A. Richards, the Doctor of Cornell University in the USA, invented a tension meter measuring the flow of water. Although it could replace the dripper in drip irrigation and realize the control without power supply, it also had disadvantages caused by its complex structure, high cost and low sensitivity [6]. In 1980s, L.Ornstein, the professor of Washington State University developed a kind of intelligent water-saving valve named Irristat, which could meet the requirement of being cost-effective, energy-saving and of high automation without power supply. However, the inappropriate structure of Irristat made the installation and monitor difficult to be conducted during the irrigation process, thus it was unfit for promotion [8]. Currently, such a water-saving irrigation equipment characterized by low cost, energy efficiency, high automation is urgent needed in China [1].

A new type of intelligent water-saving valve without power supply had been developed since 2006 by the research team of Beijing Forestry University in China. It was characterized by high automation, low costs and no electronic control. As the core of the water-saving valve, control unit could employ the feature of water swelling and drying shrinkage of the humidity sensitive materials to open or close the inlet port to guide the irrigation. Whether to open or close the valve in time laid in timely moisture exchange between the humidity sensitive materials and soil around. Therefore, mastering the exchange rate and law between humidity sensitive materials and external environment in control unit, is of great importance to make the valve to be used better in irrigation and production.

The structure of the new type valve was shown in figure 1. The water inlet port 11 and outlet port 10 were connected at the very start. After the valve was inserted into the soil, water from outlet 10 outflowed into the soil, then penetrated to the control element 3, which meant humidity sensitive materials had absorbed water and swelled. Soon spool 7 was moved upward under the thrust caused by material expansion. Water would no longer flow into the valve when the inlet 11 was completely blocked by the conical nose of the spool 7, and then the irrigation stopped. After that, the moisture in the soil would gradually decrease with the absorption and evaporation of plants, and the moisture in the control unit 3 also would reduce because of the dehydration of material. When the material volume shrank, spool 7 would move back under the action of the back-moving spring 9, inlet 11 was gradually opened, and water flowed out again from the outlet 10 to soil. In addition, the amount of water required from plants could be controlled through the adjusting screw 1 at the rear of the valve to meet multiple needs of water for various plants in different seasons and soils, and therefore increased yields [2-4].

动化水平较低，大都是通过安装各种各样的阀，靠手工调节来控制灌溉。微灌设备的适应范围比较窄，目前的微灌设备主要集中在果菜等经济作物中，适合大田作物的微灌设备亟待研究解决。国外的微灌设备整体水平比较高，其自动控制系统大都通过采用计算机、传感器、遥感遥测等来实现[7]。虽然实现了高水平的灌溉自动化，但成本都比较高，不适合中国大部分农民使用。早在 20 世纪 40 年代，美国康奈尔大学的 L.A.Richards 博士就发明出了一种测试水势的张力计，它虽然能够取代滴灌系统中的滴头，并实现无源控制，但结构比较复杂，造价太高，而且灵敏度不高[6]。1980 年，美国华盛顿州立大学的 L.Ornstein 教授研制的无源智能控制阀 Irristat 能够实现低成本、节能、无源高自动化的要求，但由于 Irristat 自身结构的问题，使得在灌溉过程中的安装和监测比较麻烦，不适合推广普及[8]。目前，兼具低成本、节能、高自动化和适合推广普及的节水灌溉设备在国内外仍是一个亟待解决的问题[1]。

北京林业大学（中国）的研究团队从 2006 年开始研制一种新型的无需电源供给的智能节水阀门，它具有高自动化、低成本和无需电控的特点。控制单元是无电源节水阀门的核心部位，它利用其控制单元中湿敏材料吸水膨胀失水收缩的特性来开启或关闭阀门进水口，从而指导灌溉。阀门能否及时开启或关闭的关键在于控制单元内的湿敏材料与外界水分能否及时的交换，因此，掌握水分在控制单元内的湿敏材料与外界环境的交换速率及规律，对该阀门应用于生产灌溉极其必要。

无电源智能节水阀门是利用湿敏材料吸水膨胀失水收缩的特性来控制阀门的关闭和打开，结构如图 1 所示，初始时进水口和出水口为连通状态。阀门插入土壤中，水从出水口流出进入土壤后，控制元件 3 即湿敏材料吸水膨胀，阀芯 7 在材料膨胀推力的作用下向上移动，当其锥形头部将进水口 11 完全堵上时，水就不再进入设备，从而停止灌溉。土壤中的水分随着植物的吸收和蒸发会渐渐减少，根据水分平衡原理，控制元件 3 中的水分也随之减少，材料失水体积收缩，从而阀芯 7 在复位弹簧 9 的作用下反向移动，进水口渐渐打开，水从出水口流出。另外，还可以根据作物的需水量来调节阀门的调节螺钉 1，满足不同作物在不同季节、不同质地的土壤中的水分需求，进而提高作物产量[2-4]。

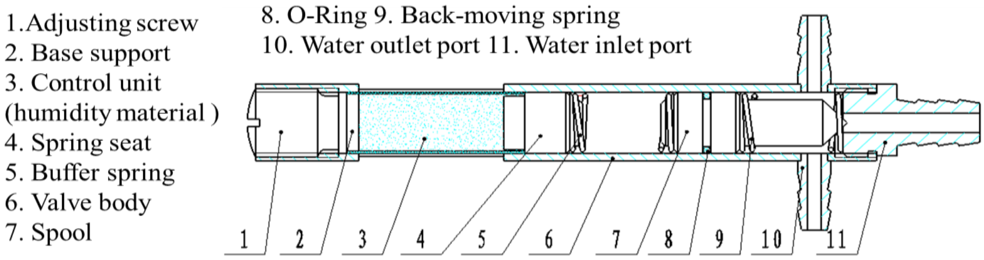


Fig.1- The structure of the intelligent water-saving valve

MATERIALS AND METHODS

Purpose of the experiment

The following experiments were designed to measure the moisture transmitting rate between humidity sensitive materials and the external environment. It has mainly studied the transmission rate between moisture and external environment at different ratio of humidity sensitive materials and different distances between the dripper and valve body. The experiment focused on the time to close the valve and to open it again at the above conditions.

Rate conversion of the experiment

The common way to get moisture transmission rate was to calculate the relationship between time and soil moisture content by using soil moisture sensor and data collector, and then obtain the result through data analysis. However, the requirement of connection between soil moisture sensor and computer made the whole system heavy and hard to operate, and the circuit was complex with limited application (shown in the figure 2, part A). So the common way was unfeasible upon all these conditions. A new way(shown in figure 2, part B) was adopted to convert the moisture transmitting rate between humidity sensitive materials and external environment to the rising rate of the valve's spool, which could also be converted to the relationship between the time and the distances (from the dripper to valve body, named C in figure2, part B). So the moisture transmitting rate would be obtained by calculating the relationship between distances and time measured from opening the dripper to closing the corresponding valve.

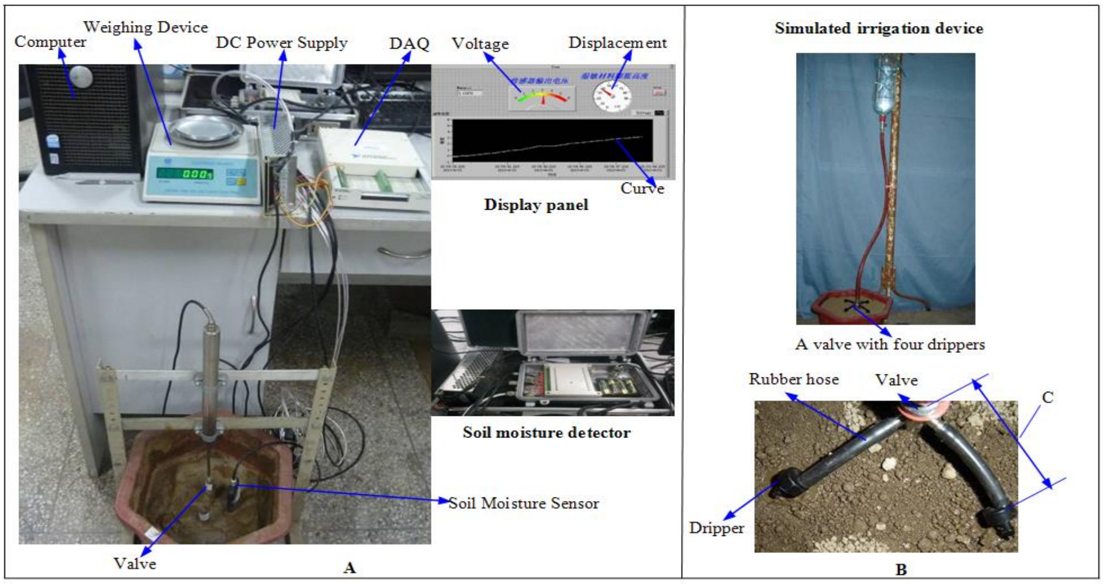
材料与方法

试验目的

本试验的目的主要是测量水分在湿敏材料与外界环境间的传输速率，主要研究无电源智能节水阀体中放置不同配比的湿敏材料以及节水阀滴口距离阀门不同距离时，水分与外界环境间的传输速率。重点在于上述条件下节水阀门的关闭和再次打开的时间。

试验速率转换

测量水分传输速度的一般做法是利用土壤水分传感器和数据采集器进行试验得出土壤含水率与时间的关系，进而进行数据分析得出试验结果，而在本试验中，由于土壤水分传感器需要与电脑连接，整个设备变得非常笨重，不便操作并且电路比较复杂，且该系统应用范围有限（见图 2，A 部分）。因此，采用了一种全新的思路（见图 2，B 部分），就是将水分在湿敏材料与外界环境间的传输速率转换为节水阀阀芯上升的速率，而节水阀阀芯上升的速率可以转换为节水阀滴口与阀门之间的距离与时间的关系。所以试验中通过采用不同的滴口与阀门距离（用 C 表示，见图 2，B 部分）进行试验，测出相应节水阀门关闭的时间，得出它们的关系，也就得出了水分在湿敏材料与外界环境间的传输速率。



Note: A. Common method of measuring system; B. A new way to get transmission rate; C. Distance between Valve body and Drippers

Fig. 2- Common and new method of measuring transmission rate

Summary of the experimental field

The experiment was conducted in vehicle internship center of Beijing Forestry University (located in Haidian District, Beijing) with the accurate position of 39 degrees north latitude, 116 degrees east longitude and the altitude of 20m to 60m. This place has a warm temperate, semi-humid and semi-arid monsoon climate with an annual mean temperature of 11～13℃, annual precipitation of 600～700mm and an annual average sunshine time of 2780.2 hours.

Experiment materials

Known from previous researchers, a kind of France water-retaining agent, named SNF, has better comprehensive performance of water swelling and drying shrinkage. It is the copolymerization of acrylamide-acrylate, which can endure for about four years [11]. Based on early research, the mixture of SNF with the diameter of 0.5mm and sand with the diameter of 1~2mm was selected as the control unit in the valve so as to increase the rate of water absorption and loss [5]. Above mixed materials which volume ratio was 1:1 and 1:3 were selected in the following experiments. Total volume was 2ml or 4ml.

Three kinds of soil at Beijing were also involved, namely sand, loam and clay, with the clearance of sand being the biggest and of clay being the smallest. The loam was produced by mixing the sand and clay with the volume ratio of 1:1.

Experimental methods

Three kinds of soil, three distances, as well as the different mixture ratio, volume, and inserting depth of the mixed materials were involved in the experiments. The whole experiment was divided into 2 categories and 45 groups.

(1)Firstly, let half part of humidity sensitive materials in the valve exposed to the air.

a) Insert a valve with humidity sensitive materials into sand soil. The distances between the dripper and valve body were respectively set to 5cm，10cm，and 20cm.

b) Mixed materials at ratio of 1:1 and the total volume 2ml or 4ml were respectively put into the control unit of the valve. When irrigation experiment was starting, time to close and open the dripper (on the valve body, seen in the figure 2(B)) again should be observed carefully and be recorded. Moisture transmission rate could be calculated through the set distances and recorded time.

c) After that, mixed materials at ratio of 1:3 and the total volume 2ml or 4ml were put into the control unit. Data should be recorded as well.

d) According to the step (a-c), conducted the above experiments in the conditions of clay soil and loam soil in order, and recorded data.

(2)Then, let the whole mixed materials into soil isolated from air.

In contrast, experiments in three kinds of soil respectively at ratio of 1:1 and volume 2ml would be done in the condition of isolated from air, i.e., the control unit including humidity sensitive material was totally inserted into soil. Also observed the time to close and open the dripper again, and recorded data.

试验地概括

试验于北京市海淀区北京林业大学车辆实习中心进行。地理位置为北纬 39 度，东经 116 度，海拔为 20~60 米，气候条件为暖温带半湿润半干旱季风气候，全年平均气温为 11～13℃，年降水量 600～700 毫米之间，年平均日照 2780.2 小时。

试验材料

在前人的研究基础上，选用粒径为 0.5mm 的法国 SNF 保水剂作为试验材料，如图 2 所示。该保水剂属于丙烯酰胺-丙烯酸盐共聚交联物，使用寿命较长，可维持 4 年左右[11]。根据前期研究，选取粒径 1~2mm 的砂石与 SNF 混合作为阀门控制单元中的材料，以提高控制单元的吸水和失水速率[5]。本试验中选择的材料为：SNF 与砂石混合体积比为 1:1 和 1:3，总体积为 2ml 或 4ml。

试验中涉及三种土壤，分别是砂土，壤土和粘土，三种土壤中，砂土的间隙最大，粘土的间隙最小，壤土的间隙居中，并且壤土是砂土与粘土按体积 1:1 混合而得到的。

试验方法

试验中涉及三种土壤，三种距离，两种湿敏材料的配比，两种湿敏材料的体积，两种湿敏材料的插入深度，整个试验可分为 2 大类 45 组。

（1）先将湿敏材料的一半与空气接触进行试验。

a）具体操作：将节水阀插入砂土中，其滴口与阀体距离分别为 5cm，10cm，20cm。

b）将比例为 1:1 总体积为 2ml 或 4ml 的混合湿敏材料分别放入阀门的控制单元中。然后开始灌溉试验，仔细观察节水阀门关闭和再次打开的时间，并记录数据。通过预设的距离以及时间就可以计算出水分传输的速率。

c）接下来，选用比例 1:3 总体积为 2ml 或 4ml 的混合湿敏材料放入阀门的控制单元中，同样记录节水阀门关闭和再次打开的时间数据。

d）按照步骤（a-c），依次在上述条件下进行粘土和壤土的试验，并记录数据。

（2）然后，将整个阀门控制单元插入土中，即湿敏材料与空气完全隔离。

该部分作为对照组，进行的是节水阀中的湿敏材料与空气不接触，即阀体完全插入土壤中，混合湿敏材料比例为 1:1 总体积为 2ml，依次在上述三种土壤中的试验，观察节水阀门关闭时间和再次打开的时间并记录数据。

RESULTS AND DISCUSSIONS

Overall results of the experiment

The results of test (1) and (2) above were shown in Table 1 and Table 2. Analyses results were mainly reflected in the figure, shown in the following.

结果与分析

总体试验结果

表 1 和 2 列出了上述试验所得的结果。分析结果主要以下图表示。

Table 1

Data of test (1) in which half part of the humidity sensitive materials were exposed to the air

Serial No.	Volume ratio	Volume/ml	Distance between dripper and valve /cm	Type of soil	Time to close/h	Time to open/h	Temperature /humidity when closed	Temperature /humidity when opened
1	1:1	2	5	sand	3.5	89	11 °C 63%	12 °C/53%
2	1:1	2	10	sand	4.5	91	11 °C /75%	11 °C /52%
3	1:1	2	20	sand	8	109	12 °C /76%	13 °C /77%
4	1:1	4	5	sand	3	91	13 °C /77%	14 °C /89%
5	1:1	4	10	sand	5	95	14 °C /78%	11 °C /63%
6	1:1	4	20	sand	6	101	12 °C /65%	12 °C /76%
7	1:3	2	5	sand	4.5	87	11 °C /63%	12 °C /53%
8	1:3	2	10	sand	6	88.5	11 °C /75%	11 °C /52%
9	1:3	2	20	sand	9.5	104.5	12 °C /76%	13 °C /77%
10	1:3	4	5	sand	3.5	75	13 °C /77%	14 °C /89%
11	1:3	4	10	sand	5.5	78	14 °C /78%	13 °C /77%
12	1:3	4	20	sand	7	92	15 °C /89%	15 °C /89%
13	1:1	2	5	clay	6	97	13 °C /66%	12 °C /76%
14	1:1	2	10	clay	8	104	12 °C /65%	13 °C /77%
15	1:1	2	20	clay	10	121	13 °C /77%	11 °C /63%
16	1:1	4	5	clay	4.5	101	12 °C /65%	13 °C /66%
17	1:1	4	10	clay	7	109	12 °C /76%	14 °C /67%
18	1:1	4	20	clay	8	131	13 °C /66%	13 °C /77%
19	1:3	2	5	clay	7.5	95.5	13 °C /66%	12 °C /76%
20	1:3	2	10	clay	10	100	12 °C /65%	13 °C /77%
21	1:3	2	20	clay	12	117	13 °C /77%	11 °C /63%
22	1:3	4	5	clay	6.5	95	12 °C /65%	13 °C /66%
23	1:3	4	10	clay	8	107	12 °C /76%	14 °C /67%
24	1:3	4	20	clay	9.5	129.5	13 °C /66%	13 °C /77%
25	1:1	2	5	loam	4	95	11 °C /63%	12 °C /65%
26	1:1	2	10	loam	6	100	12 °C /65%	12 °C /53%
27	1:1	2	20	loam	9	118	11 °C /63%	13 °C /66%
28	1:1	4	5	loam	4	95	13 °C /77%	13 °C /77%
29	1:1	4	10	loam	6	102	14 °C /78%	14 °C /78%
30	1:1	4	20	loam	7	115	13 °C /77%	15 °C /89%
31	1:3	2	5	loam	6	89	11 °C /63%	12 °C /65%
32	1:3	2	10	loam	8	94	12 °C /65%	12 °C /53%
33	1:3	2	20	loam	10	110	11 °C /63%	13 °C /66%
34	1:3	4	5	loam	5	78	13 °C /77%	13 °C /77%
35	1:3	4	10	loam	7	90	14 °C /78%	15 °C /89%
36	1:3	4	20	loam	8	112	15 °C /89%	16 °C /89%

Table 2

Experimental data of humidity sensitive materials completely inserted into the soil in the control groups

Serial No.	Volume ratio	volume/ml	Distance between dripper and valve /cm	Type of soil	Time to close/h	Time to open/h	Temperature /humidity when closed	Temperature /humidity when opened
1	1:1	2	5	sand	5	92	15 °C /78%	15 °C /89%
2	1:1	2	10	sand	6.5	99	16 °C /89%	17 °C /90%
3	1:1	2	20	sand	9	115	15 °C /89%	16 °C /79%
4	1:1	2	5	clay	8	101	14 °C /78%	14 °C /78%
5	1:1	2	10	clay	9	112	15 °C /89%	15 °C /78%
6	1:1	2	20	clay	12	123	16 °C /89%	16 °C /89%
7	1:1	2	5	loam	7	97	16 °C /89%	16 °C /89%
8	1:1	2	10	loam	8	110	15 °C /78%	17 °C /90%
9	1:1	2	20	loam	10.5	122	17 °C /90%	15 °C /78%

The relationship between transmission rate and type of soil

From the data obtained from the experiment, it could be known the relationship between type of soil and moisture transmission rate between humidity sensitive materials and soils.

Figure 3 and 4 displayed the rising rate and falling rate of the valve's spool (that is, the rate of closing and opening the valve again) at the mixture ratio of 1:1 and volume 2ml when half of the humidity sensitive materials were contacted with air. In the figure, X-axis and Y-axis separately denoted the distance between dripper and valve body with unit cm and the time (to close and open the dripper again) with unit hour.

传输速率与土壤种类之间的关系

根据试验所得到的数据可以得知水分在湿敏材料与土壤之间的传输速率与土壤种类之间的关系。

图 3 和 4 表明了在混合比为 1:1、体积为 2ml、湿敏材料一半与空气接触的条件下，节水阀阀芯的上升和下降速率（即阀门关闭和再次打开的速率）。图中，X 轴表示滴口与阀门的距离，单位为 cm，Y 轴表示经历时间，即节水阀门关闭和再次打开的时间，单位为 h。

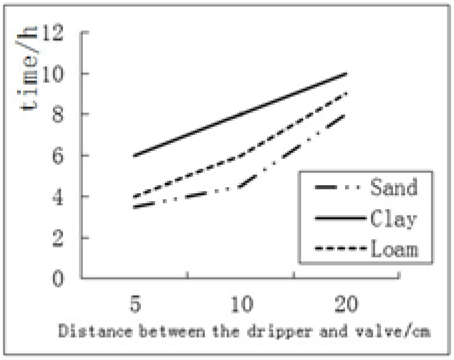


Fig.3- Rising rate of the spool

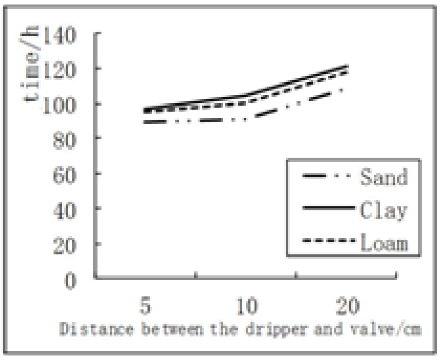


Fig.4- Falling rate of the spool

Seen from the figure 3 and 4, time to close the valve or open it again in sand soil was shortest while in clay soil was longest at the same distance between dripper and valve body, which illustrated that the fastest moisture transmission rate between humidity sensitive materials and soils could be found in sand and the slowest in clay. Same conclusion should be obtained after observing the data in Table 1 and Table 2 at different type of soil but with same ratio, volume and area contacted with air.

This phenomenon results from the different clearance of three types of soils. It was easy to find that the biggest clearance was in sand and the smallest in clay. So moisture transmission rate was the fastest in sand, and moisture could reach into the valve at the fastest speed and make humidity sensitive materials in valve swell

由图 3 和图 4 可以看出，在相同的滴口与阀体距离的条件下，在砂土中节水阀关闭所需时间最短，在粘土中阀门关闭所需时间最长，在壤土中居中。这说明了水分在湿敏材料与土壤间的传输速率，在砂土中最快，在粘土中最慢。通过观察表 1 和表 2 中的数据，在湿敏材料配比相同，体积相同，湿敏材料与空气的接触面积相同，而土壤种类不同的情况下，同样可以得到相同结论。

这样现象的产生，主要是因为三种土壤的间隙不同而导致的。我们可以很容易发现，三种土壤中，砂土的土壤间隙最大，水分在砂土中传输速率最快，所以水分可以以最快的速度到达节水阀中，并与湿敏材料接触，使得湿敏

quickly. But on the contrary, with transmission rate being the slowest in clay, humidity sensitive materials swell slowly. For the same reason, moisture evaporation speed was the fastest after the closure of the valve due to the big clearance in sand. Therefore, humidity sensitive materials had the fastest dehydration speed and the shortest time to open the valve again. However, the slow moisture evaporation rate caused by small clearance in clay would result in a longer time of dehydration and shrinkage, and a longer time to open the valve again. The clearance in loan fell somewhere between the sand and clay.

材料最快膨胀；而粘土间隙最小，水分在粘土中传输速率最慢，所以湿敏材料膨胀速率最慢；同样的道理，因为砂土间隙大，所以在节水阀门关闭后，水分从砂土中蒸发的速度也最快，所以湿敏材料能最快脱水收缩，所以砂土中节水阀门再次打开所需的时间最短，而粘土则因间隙小，水分蒸发慢导致湿敏材料脱水收缩的时间变长，所以节水阀门再次打开的时间长，而壤土间隙介于二者之间，所以所需时间也处在砂土与粘土之间。

The relationship between transmission rate and ratio of humidity of sensitive materials

The relationship between transmission rate and ratio of humidity of sensitive materials would be analyzed by using the data obtained from the experiment. Figure 5-10 indicated the rising rate and falling rate of the valve’s spool in three types of soils at the mixed ratio of 1:1 and volume 2ml when half of the humidity sensitive materials contacted with air.

传输速率与湿敏材料配比之间的关系

利用试验所得到的数据可以分析出水分传输速率和湿敏材料配比的关系。图 5-10 表示在混合比为 1:1、体积为 2ml、湿敏材料一半与空气接触的条件下，节水阀阀芯在三种土壤类型中上升和下降速率。

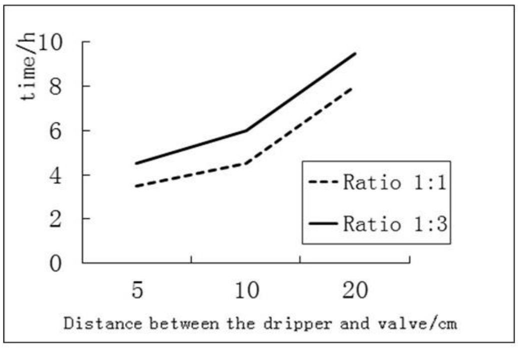


Fig.5- The spool’s rising rate in sand soil

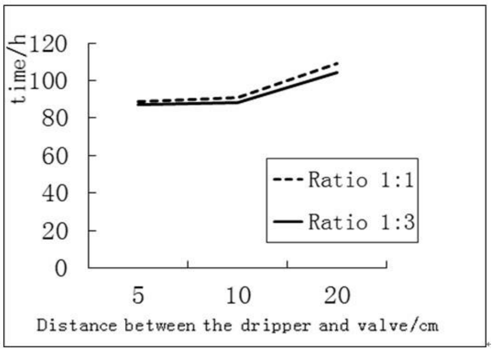


Fig.6- The spool’s falling rate in sand soil

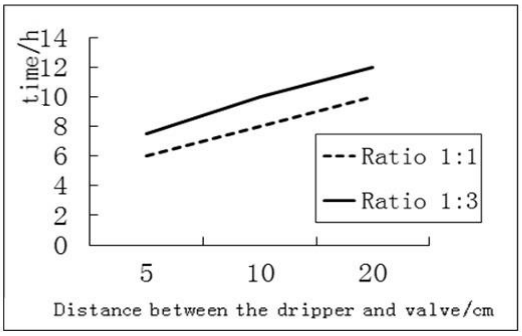


Fig.7- The spool’s rising rate in clay soil

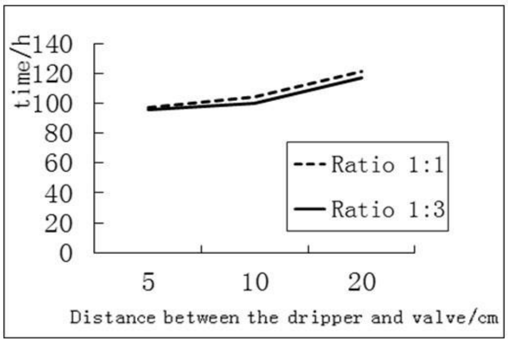


Fig.8- The spool’s falling rate in clay soil

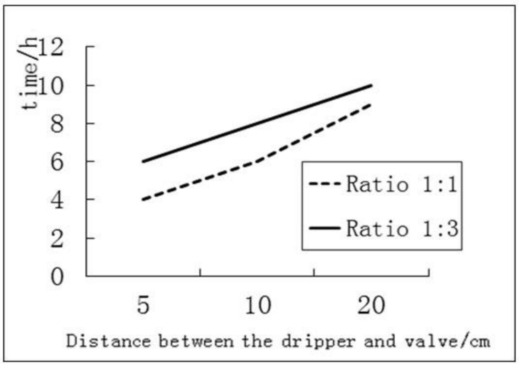


Fig.9- The spool’s rising rate in loam soil

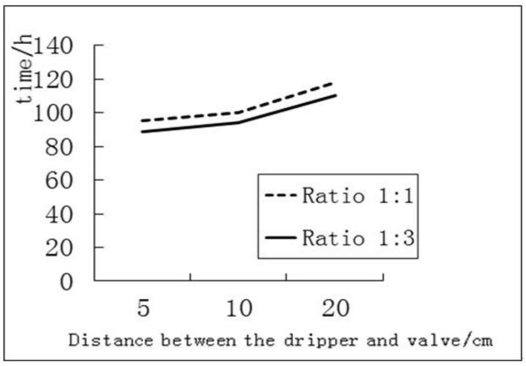


Fig.10- The spool’s falling rate in loam soil

It could be obtained from figure 5-10 that the spool has risen faster at the mixed ratio of humidity sensitive materials 1:1 than that of 1:3, and fell slower when the ratio was 1:1 than that of 1:3 under the same conditions. The expansion amount of the mixture materials was larger because of more SNF at higher mixed ratio. Shrinkage was less because more SNF needed to dry in the valve, so time to open the valve again would be longer, and the spool had a slower moving.

The relationship between transmission rate and whether humidity sensitive materials exposed to the air

Based on the mixture materials contacting the air or not, an analysis was done comparatively to the condition of volume 2ml, ratio 1:1. Analysis results of the three types of soils were shown in figure 11-16.

由图 5-10 中可以看出，对于三种土壤，湿敏材料体积为2ml，配比 1:1 与配比 1:3 比较，对于土壤达到相同的湿度，在其他条件相同时，节水阀阀芯上升速率在配比 1:1 时比配比 1:3 时快，节水阀阀芯下降速率在配比 1:1 时比配比 1:3 时慢。因为在其他条件相同的情况下，比例越大，保水剂越多，吸水膨胀的越快。节水阀阀芯上升速率越快；同理，因为体积比大湿敏材料多，脱水收缩所需的时间变多，所以节水阀门再次打开所需时间增加，节水阀阀芯下降速率变慢。

传输速率与湿敏材料和空气接触与否的关系

针对湿敏材料与空气接触与否，在混合比为 1:1 体积 2ml 的条件下进行比对分析。三种土壤的分析结果如图 11-16 所示。

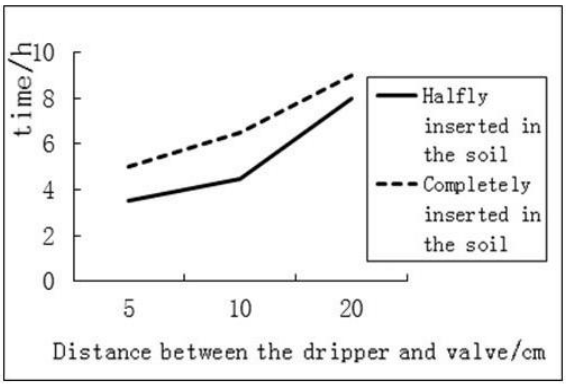


Fig.11- The spool's rising rate in sand soil

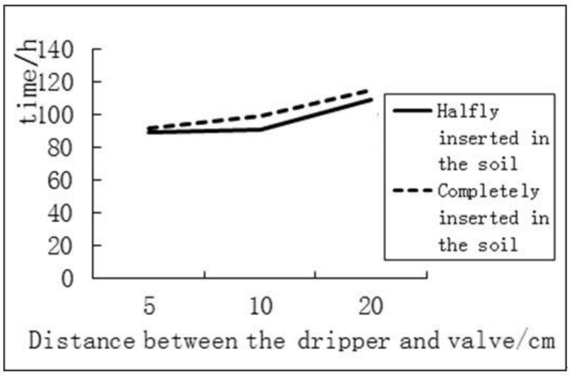


Fig.12- The spool's falling rate in sand soil

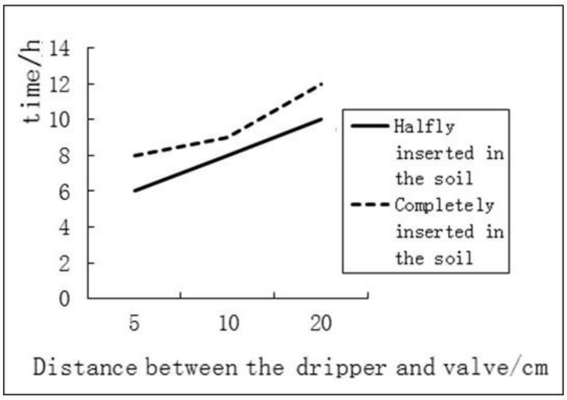


Fig.13- The spool's rising rate in clay soil

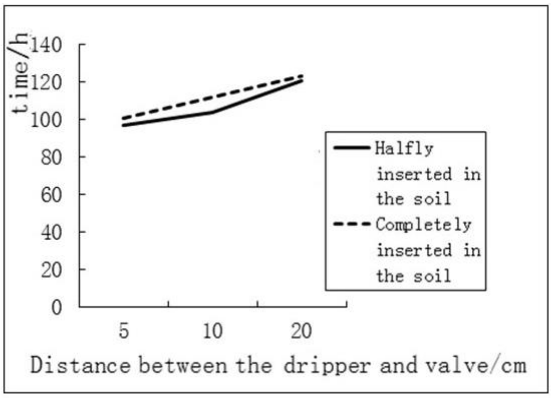


Fig.14- The spool's falling rate in clay soil

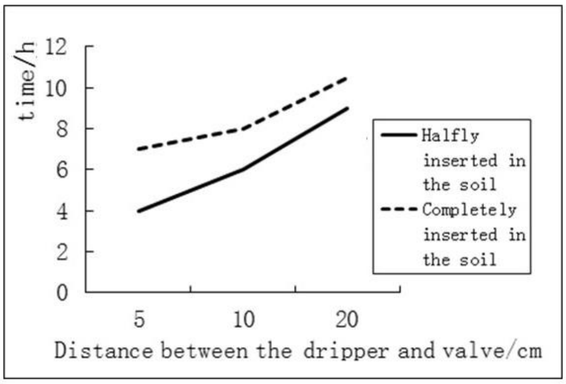


Fig.15- The spool's rising rate in loam soil

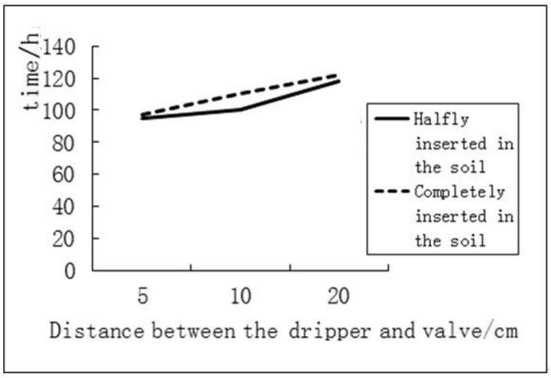


Fig.16- The spool's falling rate in loam soil

It could be seen from figure 11-16 that the spool rose or fell faster when the mixture materials in valve contacted the air in all three soils at the mixing ratio of 1:1 and volume 2ml, which indicated that moisture transmission rate between humidity sensitive materials and external environment was faster when the valve half inserted into soil. It was mainly because that moisture needed evaporation after the closure of the valve caused by a certain degree of soil moisture, then the valve should be opened again. In the process, the humidity of air was less than that of soil, so humidity sensitive materials contacted with air had a faster dehydration speed, a shorter shrinkage time and a shorter time to open the valve again.

CONCLUSIONS

The new valve type was developed with the idea of water saving and energy conservation, which could control irrigation on-off without computer and sensors. It was especially suitable for popularization and promotion in agricultural and forestry irrigation of poor condition area.

Following conclusions were mainly found that moisture transmitting rate between humidity sensitive materials and the soils or the air was influenced by clearance of the soil, ratio of humidity sensitive materials, and whether exposure to the air through the above experiments and analyses.

(1)The fastest transmission rate of moisture between humidity sensitive materials and soil could be found in sand and the slowest in clay for different kinds of soils.

(2) The speed of material water-absorption was faster when its ratio was 1:1 than that of 1:3, and speed of material water-loss was slower at the ratio 1:1 than that of 1:3.

(3) The transmission rate of moisture was faster when contacting with air. Besides, a general time range (time to close the valve from 3 to 12 hours and time to open it again from 70 to 130 hours) could be summarized from the experimental data.

It would provide reference for the further application of the new water-saving valve, and it is helpful to develop rapidly water-and energy-efficient technologies to promote the steady and efficient development of agriculture and forestry products.

ACKNOWLEDGEMENT

The financial support of the Fundamental Research Funds for the Central Universities (No. YX2011-6) is gratefully acknowledged.

REFERENCES

[1]. Junjun Li. (2009) - *Study on Mechanical Properties of Control Unit of Control Valves without Power Supply*, Beijing Forestry University;

[2]. Junjun Li, Guosheng Yu. (2008) - *Experimental Study on Mechanical Proper ties of Control Unit of Control Valves without Power Supply*, Forestry Machinery & Woodworking Equipment. vol. 36, no.10, pp.12-15;

从图 11-16 中可以看出，在其他条件相同时，湿敏材料体积 2ml，比例为 1:1 的情况下，对于三种土壤而言，湿敏材料有一半与空气接触时节水阀阀芯上升速率快于湿敏材料完全不与空气接触的情况，当湿敏材料有一半与空气接触时，节水阀阀芯下降的速率比湿敏材料完全不与空气接触时的快。也就是说明湿敏材料与空气接触，则水分在湿敏材料与外界的传输速率越快。出现这样的结果，主要是因为当土壤湿润到一定程度，节水阀关闭后，水分需要蒸发，节水阀才能再次打开，此时空气的湿度小于土壤湿度，所以与空气接触的湿敏材料脱水速度变快，所以收缩的时间变短，节水阀再次打开所需时间变少。

结论

本文研制了一种无需计算机和传感器控制阀门开关的新型阀门，它以节水节能为本，尤其适于在落后条件的农业和林业地区推广和实施。

通过上述试验分析，可以得到无源智能节水阀门工作时，水分在湿敏材料与土壤和空气间传输速率与土壤间隙，湿敏材料配比，湿敏材料与空气接触与否三个影响因素的一些结论。

（1）对于不同的土壤种类，水分在湿敏材料和土壤之间传输速率在砂土中最快，而在壤土中最慢。

（2）对于湿敏材料的不同配比，对于材料吸水速率在配比 1:1 时比配比 1:3 时快，材料失水速率在配比 1:1 时比配比 1:3 时慢。

（3）对于湿敏材料是否与空气接触两种情况，与空气接触时的水分传输速率较快。同时，从试验数据可以总结出节水阀门关闭和再次打开大体有一个时间范围，基本上在 3 小时到 12 小时的范围内能够关闭，节水阀门再次打开也有一个范围大体上在 70 个小时到 130 个小时之间。

该研究可为新型节水阀门的进一步应用提供参考，同时，对于发展节水节能技术以提高农林业产品的稳步高效发展也很有帮助。

致谢

本文受到中央高校基本科研业务费专项资金资助（项目号：No. YX2011-6）。

参考文献

[1]. 李俊俊. (2009) - *无电源节水阀门控制单元性能研究[D]*. 北京林业大学机械设计及理论专业硕士论文, 中国, 北京;

[2]. 李俊俊, 俞国胜.(2008) - *无电源控制阀门控制单元力学性能实验研究*, 林业机械与木工设备, 第 36 卷, 第 10 期, 12-15;

[3]. Ke Du, Xiangyue Yuan. (2011) - *Advances in Passive Control of Water Saving Irrigation Valve*, Hunan Agricultural Sciences, vol.23, no.11, pp.136-138;

[4]. Ke Du, Guosheng Yu, Xiangyue Yuan. (2013) - *Research on the Control Mechanism of Intelligent Water-saving Valve Control Elements*, Forestry Machinery & Woodworking Equipment, vol. 41, no. 9, pp.36-38;

[5]. Ke Du. (2013) - *Research in Wet Sensitivity of Humidity Control Component of Intelligent Water-saving Valve*, Beijing Forestry University.

[6]. Ornstein L. (1985) - *The Irristat: A moisture-sensitive self-regulating water valve for drip irrigation systems*, vol II, Proceedings Third International Drip/Trickly Irrigation Congress, Fresno, CA. ASAE, Nov. 17-21, pp.623-629;

[7]. Patamanska, G, Chehlarova-Simeonova, S. (2012)- *Changing existing irrigation systems and management in Bulgaria for sustainable use of water*, INMATEH - Agricultural Engineering, v 38, n 3, pp.73-78;

[8]. Robert G, Edward L, Marty W. (1986) - Water-sensitive valves for monitoring crop water use pattern, ASAE Technical Paper 86-2572. Presented at Winter Meeting of ASAE, Chicago, IL. Dec.16-19, pp.1-14;

[9]. Shuhui Luo. (2012) - *Face the Challenges of Water Resources*, WTO Economic Herald, no.5,pp.77-78;

[10]. Tingjun Wang, Weizhan Zhang. (2012) - *Status and Ways of Water Saving in Agriculture*, Beijing Agriculture, no.9, pp.149;

[11]. Xiaosan Liu, Chuan Ye, Guobin Xiao. (2012) - *Effect on the soil moisture and growth of autumn glutinous maize and polyacrylamide water retaining agent*, Chinese Agricultural Science Bulletin, no.30, pp.22-27.

[3]. 杜珂,袁湘月. (2011) - *无源控制节水灌溉装置研究进展*, 湖南农业科学, 第 23 卷, 第 11 期, 136-138;

[4]. 杜珂,俞国胜,袁湘月. (2013) - *智能节水阀门控制元件控制机理研究,* 林业机械与木工设备, 第 41 卷, 第 9 期, 36-38;

[5]. 杜珂. (2013) - *智能节水阀门湿敏控制元件湿感灵敏度的研究,* 北京林业大学机械设计及理论专业硕士论文, 中国, 北京.

[6]. Ornstein L. (1985) – *一种湿敏自调节滴灌阀门系统[A]*. 世界第三届滴灌会议第 2 卷[C], 美国加州夫勒斯诺市: 美国农业工程师协会,1985 年 12 月. 17-21, 623-629;

[7]. Patamanska, G, Chehlarova-Simeonova, S. (2012) - *改变灌溉系统和管理提高水资源可持续利用*, INMATEH - 农业工程, 第 38 卷, 第 3 期, 73-78;

[8]. Robert G, Edward L, Marty W. (1986) – *水分控制阀门监测作物需水模式 [A]*. 美国农业工程师协会冬季技术会议论文[C], 美国伊利诺伊州芝加哥: 美国农业工程师协会,1986 年 12 月 16 日-19 日, 1-14

[9]. 罗曙辉. (2012) - *应对水资源挑战,* WTO 经济导刊, 第 5 期, 77-78;

[10]. 王庭俊, 张伟战. (2012) - *我国农业用水现状及节水途径*, 北京农业, 第 9 期, 149;

[11]. 刘小三, 叶川, 肖国滨, 等. (2012) - *聚丙烯酰胺型保水剂对土壤水分及秋糯玉米生长的效应,* 中国农学通报, 第 28 卷, 第 30 期 , 22-27.