Condensation Irrigation Field Test - Measurements of Soil Moisture

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Abstract

Due to the increasing scarcity of fresh water in arid areas, desalination of saline water is inevitable. Condensation irrigation combines desalination and irrigation. In the condensation irrigation system, solar energy heats the saline water of a water still. Air is humidified by flowing over the warm saline water. This humidified airflow is pumped into buried drainage pipes, where the airflow cools and condenses along the pipe surface. Then the precipitated water penetrates the surrounding soil through the holes in the pipe wall and irrigates the surrounding soil. In this current study, the available and useful moisture was measured by TDR above the soil pipe. The resulting rate of Irrigation or obtained water was 1.5 mm/day after 15 days.

Keywords: Condensation, Irrigation, Desalination, Renewable Energy, Moisture.

Introduction

Water scarcity is one of the most important issues in the arid and warm parts of the world, e.g. the Middle East and North Africa and new resources of water must be found (Anderson & Watson, 2013). Also in arid and semi-arid areas, the fresh water demand is increasing with the growing population (Kuylenstierna et al., 2009; Kahl et al., 2016) and the need to solve this water problem is urgent.

For the future, desalination of sea water is the only foreseeable large-scale option (Lindblom, 2012; Yousefi, 2012). However, the financial and environmental cost of fossil energy in these systems are also increasing (Grubert et al., 2015). Therefore, renewable energy systems must be developed. Solar desalination system is one future way for the production of freshwater (Lindblom, 2012; Lindblom, 2006; Yousefi et al., 2012) and Condensation Irrigation (CI) is such a system.

Condensation Irrigation (CI)

The CI system uses solar thermal energy to evaporate saline or otherwise impure water, in solar stills. Ambient air is humidified by the warm water inside the still and thereafter led into an underground pipe system where it is
cooled and the vapor condenses as freshwater on the inner pipe walls (Lindblom, 2012). Condensed freshwater can be collected at the end of pipe if common pipes are used (Lindblom, 2006; Yousefi & Boroomand-Nasab, 2015) or otherwise it penetrates the soil through perforations of the drainage pipe (Lindblom & Nordell, 2006; Yousefi, 2012). This subsurface irrigation method significantly reduces evaporation from the soil surface.

![Figure 1. Outline of CI system (Lindblom, 2006).](image)

The first research on condensation Irrigation (CI) was started at Luleå University of Technology (LTU). The principles of CI was published by Widegren (1986), which also concluded that it would be possible to irrigate 1 ha of land with a total fan power of 3-10 kW. Göhlman (1987) studied the different heat transfer in common and perforated pipes and showed the heat transfer in the perforated pipes was twice as high thus proving a higher condensation rate. Nordell (1987) used the CI technology in the construction of a climate system for a cucumber greenhouse, at the polar circle in Sweden. The idea was to reduce the air temperature variation between day and night and it was operating successfully for about 20 years.

Hausherr and Ruess (1993) describes a CI plant in Switzerland and it shows that this CI system reduced the water consumption of a tomato greenhouse by 50%. In a master thesis by Gustafsson and Lindblom (2001) the feasibility of using humid-warm air for subsurface irrigation was investigated. Other experiments were made by the National Research Institute for Agricultural Engineering in Tunisia. They found the most important characters affecting the water production efficiency are inlet air temperature and humidity (Chaibi, 2013). A Matlab model, CI2D, was developed to simulate heat and mass transfer in Condensation Irrigation system by Lindblom (2012). Yousefi (2012) made a field test in Iran, in a CI system with a pipe length of 25 meters. The resulting daily production per pipe was 4.0 and 6.0 l, drinking water and irrigation water, respectively.

**Objectives**

In previously performed studies, the purpose was to investigate the feasibility and performance of the CI system. This included total water production in the CI system but part of this produced water was infiltrated into the soil through the bottom holes and was out of reach. The aim of current research is to show the rate of Irrigation or obtained water above the drainage pipe (root zone). Suggestions of how to improve the CI system are also presented.

**Methodology**

**Study area**

Ahvaz is located in SW Iran (31°20′N, 48°40′E). The average annual temperature and precipitation are 25.3°C and 241 mm, respectively (IRIMO, 2007). The study was conducted at the Shahid Chamran University (SCU) farm, during 2012. The soil texture at the site is fine loam. Its porosity and initial moisture content were 39.5% and 18%, respectively.

**Installation and operation**

As a first step to install the CI system, a ditch was plowed with a length of 25 m and 0.4m depth (Fig. 2). A PVC drainage pipe with a diameter of 63 mm was placed at the bottom of this trench.
Originally the drainage pipe was an un-perforated pipe in which holes were drilled with a diameter of 5 mm. After the installation, the trench was refilled with soil (Fig.2). Then a solar still and a fan with a power of 16W and 65 m$^3$/h flow rate were installed and was connected to the thermally conducting the humid air to the drainage pipe.

**Subsurface irrigation**

The combination of solar energy and an electrical heater created stable conditions in heating the water of the still. The humidified airflow was driven through the drainage pipe during 8 h/day. Hence the humid was condensing on the inside the drainage pipe. In this case, condensed water and part of humid airflow penetrated to the surrounding soil. Thus the subsurface soil was irrigated and aerated although it was warmed as well.

**Measurements**

To calculate condensed water in the drainage pipe, a set of parameters was measured hourly, these included the relative humidity, temperature and velocity of humid airflow. As previously mentioned, the main aim was measuring of available moisture and observing moisture distribution in the soil above the pipe. Therefore, to obtain more information about the calculations of condensed water in the pipe, see (Lindblom, 2006; 2012; Yousefi, 2012).

Humidity probes were installed at the 5 and 15 cm above the pipe in the soil, with 6.25 m spacing along the drainage pipe (i.e. 6.25 m, 12.5 etc., see Fig. 3) to enable monitoring moisture variations above the pipe (Fig. 3). It should be noted that these measurements were done at the end of each day by Time Domain Reflectometry (TDR). The TDR gives volumetric moisture content (water content) in the area with, a diameter of 10 cm, around each probe (Topp & Davis, 1985).
So the available moisture in the soil layer, \( d \) (mm), is defined through the following equation:

\[
\delta = (\theta_{v2} - \theta_{v1}) \times D \times 1000
\] (1)

Where, \( \theta_{v2} \), \( \theta_{v1} \) are the initial and resulting volumetric moisture contents (%) in the soil, respectively, and \( D \) (m) is the depth of soil layer. Therefore in current test, the moisture content of the soil was measured in separate layers because available soil moisture could be obtained more accurately and evaporation from underground irrigation systems is generally low.

**Results**

The accumulated increase in soil moisture at the 5 and 15 cm distance above the pipe, with time and also along the pipe, are shown in Fig. 4 and 5. It is seen that the soil moisture is increasing relatively constant.

Obtained results (see Eq. 1) showed that the average increased available moisture in the soil varied from 32 % at the beginning to 6 % at the end of pipe in the first 10 cm layer, during 15 days. This moisture change corresponds to an average irrigation of 1 mm/day. It is also seen the accumulated moisture along the pipe is much lower at the end which indicates that most of the humidity had condensed before it reached halfway along the pipe. A fan with a higher capacity would have moved the humidity further down the pipe.
Fig. 5 is showing, the average available moisture increased by 17% at the beginning while it only increased by 2% at the end of pipe in the second layer, located 10 – 20 cm from the pipe, during 15 days. As it was mentioned previously, in this layer the average rate of irrigation it was estimated to 0.5 mm/day.

So it can be concluded that the average obtained water production in the 25 m above drainage pipe was thus 1.5 mm/day, to be compared with previous work by Lindblom (2012) who achieved 2.26 mm/day in a 50 m long around drainage pipe in a sandy soil. In the current field test, the irrigation rate was lower though it is difficult to compare the two tests, with different dimensions, climate, soil type and moisture measurements location. Also in comparison with Yousefi (2012) who showed the average obtained water in a 10 cm layer around the pipe was 1.82 mm/day, this study results show that about 45% of the irrigated water was lost in the soil under the pipe which is not available for many of plants.

In Fig. 4 and Fig. 5 it was also seen that the soil moisture content along the first 12.25 m of the pipe increased much more than along the remaining 12.25 meters. So, it is concluded that if the pipe length had been halved, the average obtained water could have been increased to 2 mm/day. On the other hand, one conclusion of this observation is that a more powerful fan would have resulted in greater water production. Also, it would be useful if you decrease the depth of pipe to 20 cm, then the roots can absorb more water from the area around the pipe too.

The photo in Fig. 6 shows that the soil moisture around the pipe has reached several diameters from the pipe.
Conclusion

Condensation Irrigation is a new method that combines desalination and irrigation. In this CI study, the available soil moisture production was investigated, at 5 and 15 cm, above the drainage pipe. Performed tests resulted in a daily mean available soil moisture production rate of 1.5 mm/day along the 25 m long pipe. The water production was 1 mm/day and 0.5 mm/day in the first and second layer, respectively. It was also shown that the available soil moisture content along the pipe decreased. Due to the low moisture at the second half of drainage pipe, it was concluded that a more powerful fan should have been used for the 25 m pipe. Also, further CI studies are necessary to investigate its feasibility as an irrigation system for this region.

Conflict of interest
The authors declare no conflict of interest.

References