Hydro-osmotic Potential Irrigation System (HOPIS)

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Abstract- A micro auto regulative irrigation technology has been examined in Iraqi soils namely *Hyro-Osmotic Irrigation System HOPIS.* Experimental field measurements have been conducted to investigate the physical Wetting front advance behavior (issued from ceramic jar) through three types of soil; they are clayey, sandy, and mixture of (40%clay, 40%sand and 20% fertilizer) soils under the effect of a variable hydraulic head of (0, 1.25, 2.5m).

The experiments proved that HOPIS is an effective irrigable technology in dry and desert regions for both supplying and conservation of water everywhere water scarcity is occurred and its attainability is of difficult challenge.

It is found that the Wetting front reaches a distance of 6cm, 10m, and 12.5cm with velocities 1.3, 2, 6 cm/hr after 6.5hrs since irrigation process is started under hydraulic heads of 0cm, 1.25m, and 2.5m respectively in clayey soil. It reaches a distance of 6cm, 13m, and 15cm with velocities less than 1cm/hr after 6.5hrs since irrigation process is started under hydraulic heads of 0 m, 1.25m, and 2.5m respectively in sandy soil. Whereas it reaches a distance of 4.1cm, 8.4cm, and 12.8cm with velocities less than 0.35cm/hr after 12hrs since irrigation process is started under the same hydraulic heads in a mixture soil.

Keywords: HOPIS: Osmotic Potential Irrigation System, Clay Jar, Wetting Front, Water Phase, Jar.

1. Introduction

Ceramic Jarrah was invented by farmers in Northern Africa thousands of years ago. It is a container to save water, honey …etc., since long time by human. Although human uses a modern technology to save and cool water, Jar still a good tool to natural cooling and enhancing water flavor rather than class and plastic vessels. Briefly, Jars are made of red clay and crush Basalt stone mixed with water; the mixture is masticated and left for one day to be reformulated later for required shapes.

Abu-Zreig and Atoum, (2004) constructed a mathematical model to predict seepage quantity from pitchers of different wall hydraulic conductivities range between 0.219 and 2.37 mm/d. Whereas the seepage rate from the pitchers to the atmosphere ranged from 600 to 3700 mL/d, with strong correlation factor of (R^2 =0.97) between the simulated and laboratorial data.

Majed et al (2006) carries out Laboratory experiments to quantify the influence of evaporation on the negative pressure condition in the soil, the seepage rate of pitchers and the auto-regulative capability of the pitcher irrigation system. High and low hydraulic conductivity pitcher groups are tested under varying temperature and humidity. It is found that a correlation factor of 0.97 between seepage and E_p.

Altaf et al (2009) present that small pitcher will produce the same wetting front of larger one with double volume and half hydraulic conductivity.

Bellachehhb C. (2013) talks about the buried diffuser techniques and makes a comparison between drip irrigation and other traditional irrigation methods and presents the good circumstances to be used.

Fahdil M. A.(2010) reveals that Pot irrigation by unglazed clay pots which contains a huge number of microspores in its wall for water seeping. He experimentally quantifies the effects of pot volume on water use efficiency and surface wetting front. Two types have been examined; large and small pot volume. The results show that large volume pot is more efficient than small pot.

Mahatsindry et al, (2010) studied the water balance resulting from the clay irrigation for beans and Amaranths grown under plant density per pot and precedent soil moisture. Results revealed that clay pot irrigation gives good growth for amaranths, while the same technique did not provide similar results on beans.

Shrivastava et al (2010) evaluation the pitcher irrigation on the performance of *young manga* crop. It is found that there is non-significant change during the first 4 years, only 4% mortality due to mechanical damage and disease. It is insisted by placing 2 pitchers of 7liters capacity filled every 8^{th} days shows 30% water saving and 30% less cost.

Kefa et al., (2013)," presents study to evaluate water use savings under clay pot compared to furrow irrigation methods using field trials of maize and tomato crops and soil water balance techniques. In addition an analytical salinity study of irrigation water is done. Results indicate that source irrigation water of 0.85g/l. It is found that clay pots more efficient than the furrow irrigation method by saving 97.1% and 97.8% of applied water for the maize and tomato crops respectively. The maize grain yields is 32.2% higher than that under the furrow, while fresh fruit tomato yields is 43.7% higher in the clay pot system than the furrow. Stein T. M. (2013) has outlined on pitcher irrigation and prepared long bibliography about whom work or write about pitcher irrigation system.

Fortunately, there is auto- regulative process for supplying soil with water by a clay Jar; when the soil becomes dry, suction forces of surrounding soil develop to compensate water leakage and vice versa. In another word "It's automatic irrigation without timers or electronic sensors". In this research, the wetting front advance through the unsaturated zone is experimentally tested in local Iraqi soils (clay, sand, and mixture) and its velocity is estimated by using simple mathematical bases. Fig.(1) presents how clay Jar supply plants with necessary irrigation water.

(a) (b) (c)

Fig.(1) Buried Jar bounded by plants during deferent stages of life

2. Research Significance

Nowadays, water scarcity in arid and semi-arid regions represents a major social problem over all the worldwide. People face constantly the shortage in water resources necessary for their daily activities and irrigation water demand especially in Iraq everywhere under terrorism circumstances. In addition (HOPIS) is the challenge for irrigation water scarcity especially in the Middle East anywhere people spent much time and labors to get few amount of water frequently from far places where it is available or some time the fields of uneven terrains are too difficult to be irrigated by traditional surface irrigation methods . Accordingly, the need for water saving irrigable technology is inevitable. HOPIS has proved it is ineluctable economical and irrigable tool to be used anywhere water rarity is dominant especially under terrorism problem in critical terroristic regions.

3. Full Scale of Current HOPIS

A full scale model of HOPIS can be demonstrated by the following units:-

1- Water storage tank.
2- Transmission pipes to transmit water from the water tank toward the clay Jarrahs.
3- Clay Jarrahs.

Fig.(2) shows the full model plan of HOPIS.

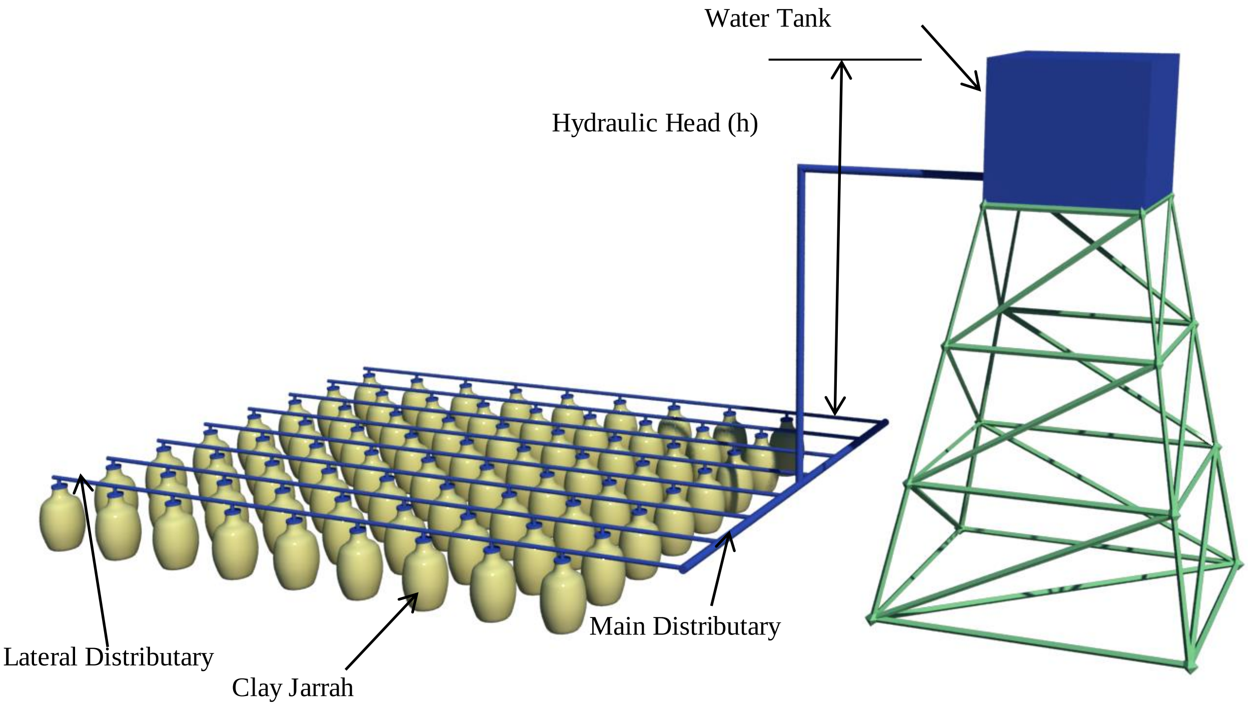

Fig.(2) Full Model Plan of HOPIS & Field Lay out

4. Clay Jar Connection

Jar represents a major unit of HOPIS. Jar should tightly be closed with plastic, clay, or concrete cover to prevent water leakage by using *Mastice Polystere* (it is preferred for its high pressure resistance) or *waterproof silicone caulk* and connects with network pipes to feed the Jars with irrigable water. Fig.(3) presents these details (in the current case z = 10cm).

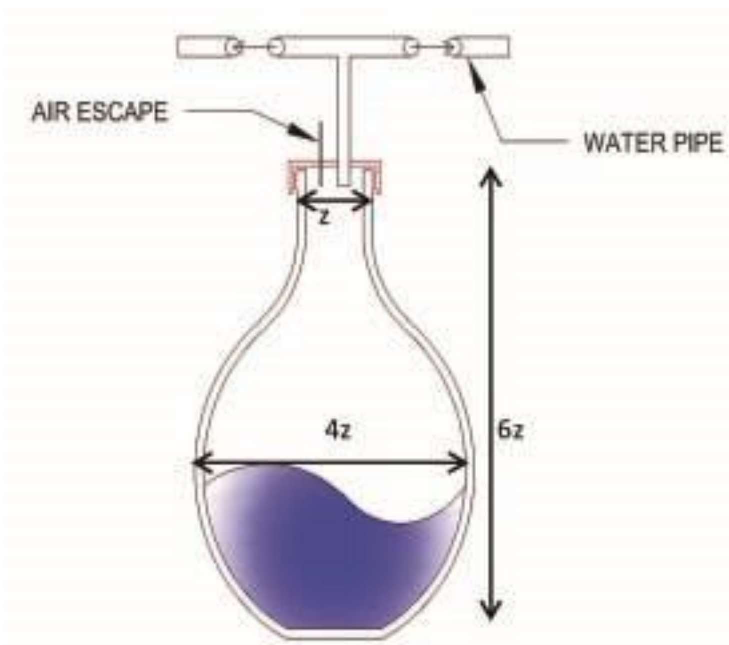

Fig.(3) Jarrah Connection Method

3.1 Osmotic Jar Details

Clay Jarrah represents the major unit in the current irrigation process. Briefly, it consists of two parts as shown in Fig.(3):-

1- Scorching clayey vessel (Jarrah).
2- Ceramic or plastic cover with water divider.

In this technology, it is suggested to paint the lower parts of the clay Jar to prevent downward deep percolation. See Fig.(3).

a. Laboratorial Determination of Jarrah's Wall Hydraulic Conductivity

Before using of the Jarrahs in HOPIS, it is preferred to estimate the hydraulic conductivity of Jarrah's wall in the laboratory. The falling head permeameter test based on Darcey' Law may be modified and arranged as in Fig.(4)

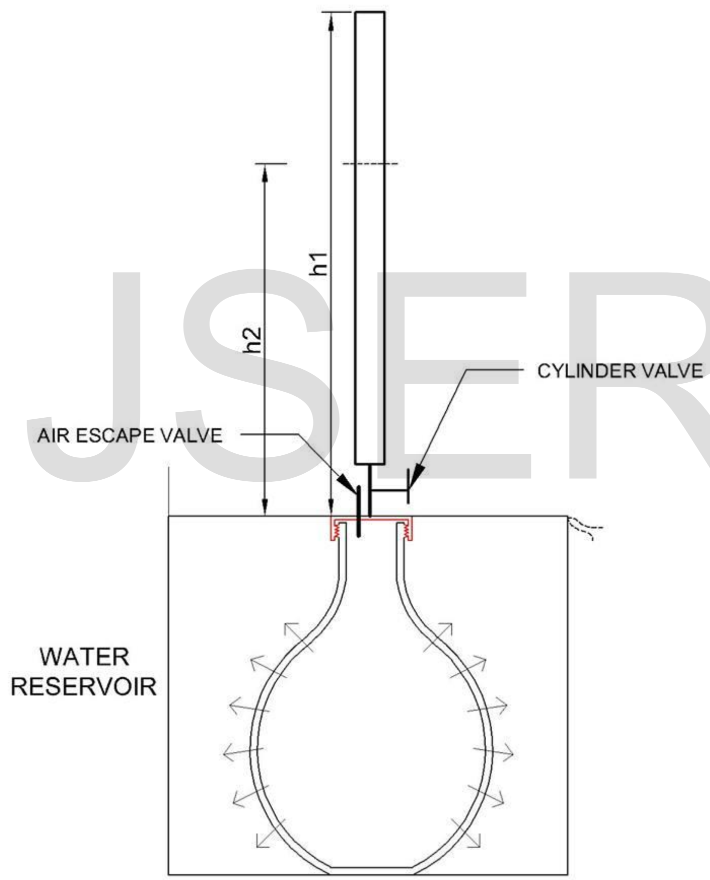

Fig.(4) Laboratorial Arrangement for Jarrah Hydraulic Conductivity Test

The Jarrah should be tightly connected to a graduated cylinder to measure water head decline during the test. The elapsed time (t) for a specified head change of water in the graduated cylinder is recorded. The inner surface area (A) and the Jarrah's wall thickness (L_g) is measured. To estimate the hydraulic conductivity of Jarrah's wall (K_g) may be estimated by Darcy's Law as follows:

$$K_g = \frac{a\,L_g}{A\,t} \ln \frac{h_1}{h_2} \qquad (1)$$

Where:- a is a cross sectional area of the graduated cylinder, A is the inner surface area of Jarrah, t is the time required for head fall, h_1, and h_2 are the initial and final hydraulic heads measured with respect to a constant water level of reservoir shown in Fig.(4).

3.3 Equivalent Inner Surface Area of Irregular Jarrah Shape

Axiomatically, Jarrah may be taken any irregular geometric shape because of its manual manufacturing. Accordingly for simplicity, any measurements and estimation the equivalent dimensions of spherical shape may be used. Firstly, the volume of Jarrah ($v = 8\ liters$) is measured by known volume of water, and then it should be equated to the volume of the sphere as follows:-

$$v = \frac{4\pi R^3}{3} \quad \ldots\ldots (2)$$

By rearranging, one may get:

$$R = 0.62 v^{\frac{1}{3}} \quad \ldots\ldots (3)$$

Where:- v is equivalent volume of sphere, and R is equivalent sphere radius.
The inner surface area (A) of equivalent sphere may be obtained by:

$$A = 4\pi R^2 \quad \ldots\ldots (4)$$

Combining Eq.(3) and Eq.(4) to obtain:-

$$A = 4\pi (0.62 v^{\frac{1}{3}})^2$$

$$A = 4.83 v^{\frac{2}{3}} \quad \ldots\ldots (5)$$

Substitute the obtained area (A) of Eq.(5) in Eq.(1) to obtained the final form

$$K_g = \frac{0.207 a\ L_g}{v^{\frac{2}{3}}\ t} \ln \frac{h_1}{h_2} \quad \ldots\ldots (6)$$

3.4 Methodology of Testing Permeability

Once, the graduated cylinder is tightly fixed to the Jarrah, and then the Jarrah should be drowned in water reservoir. The water is set into the Jarrah to be filled with water. The air escape valve must open to let air bobbles get out of the system. The valve is closed and the Jarrah is left in the reservoir for enough time to saturate its wall. To start the test, the cylinder valve is open [measure h_1, h_2, required time (t)]. It is found the tested hydraulic conductivity of Jarrah wall is 3.467e-6cm/s = 0.0125cm/hr = 0.3cm/day

4. Clay Jar Setup & Field Testing Technology

Field investigation of buried clay jar may be achieved by the following steps:-

1- A dig hole with dimensions of 1 times jar dimensions is excavated to maintain the soil in a natural condition and to guarantee no more disturbance for clayey soil to be occurred.
2- The excavated volume around the jar is filled with soil after the jar is setup immediately.
3- The hydraulic system is applied to the jar after the required tight of its opening is done.
4- Metallic rods are inserted near the jar at 5cm apart
5- The entrapped air is gotten rid of by special valve.
6- The time required for wetting front to reach each metallic rode is achieved by using the avometer, the time is recorded immediately when the electric resistance is reduced suddenly. This means that the wetting front reaches the considered rode. The arrangement is presented in Fig.(5).

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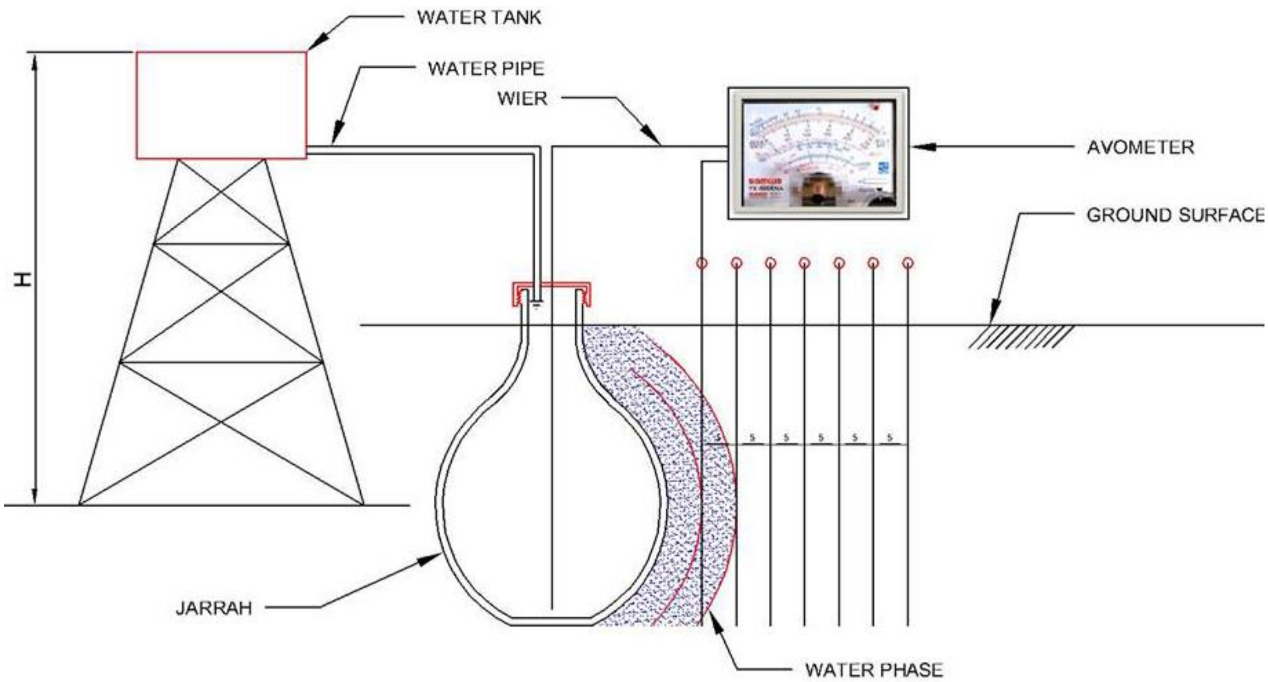

Fig.(5) Wetting front (Water Phase) Advance Measurements

5. Mechanism of Wetting front Advance & Osmotic Process

5.1 Clay Soil

Upon testing a wetting front advance through soil body of clayey soil with a natural dry density of 15.39KN/m^3, it is observed that in the beginning of the experiment, water consuming is limited or small. This is occurred within the first 20hrs but with time proceeding, water consumption increases acceleratory, until it is fixed after about 105hr to be a constant consuming rate with time as shown in Fig.(6).

The interpretation for this phenomenon is that in the beginning of this auto-regulative irrigable process, water is consumed by grains surfaces moisturization whereas immediately osmotic process is not yet started. After all pores of clay soil have been saturated, then osmotic process (osmotic pressure) considerably has been activated. It is clear that the activity of this phenomenon is oscillating depending on soil need for water. It is found that a natural logarithm curve is a best fit for this d-t relation.

5.2 Sandy Soil

The Wetting front advance is also tested under a hydraulic heads of (h=0, 1.25m, and 2.5m) in Pure sandy soil with dry natural density of 16.7 KN/m^3. The d-t relationship is represented in Fig.(7). A logarithmic relation is the best fit for such soil with correlation factors of (R= 0.9859, 0.9921, and 0.9816) respectively.

5.3 Mixture Soil

The wetting front advance is also tested for a soil mixture of (40% clay, 40% Sand and 20% Fertilizer) under the same hydraulic heads of (h=0, 1.25m, and 2.5m). A logarithmic relation of correlation factors of (R=0.9626, 0.9903, 0.9985) is the best fit of this type of soil is shown in Fig.(8).

6. Method of Wetting front Advance Measurements

6.1 Wetting front Velocity

Once, it is obviously known that wetting front distance from the jar may be taken as:

$$d = f(t) = k_1 \ln(t) + k_2 \quad \text{......} \quad (7)$$

and the velocity through soil body is:

$$v = f(t)' \quad \text{......} \quad (8)$$

Where k1, k2 are constants , v is the velocity and t is the elapse Wetting front time.

The first derivative of Eq.(7) offers Eq.(9) as follows:

$$v = \frac{dd}{dt} = \frac{k_1}{t} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

By combining Eq.(7) and Eq.(9) we may obtain:

$$v = k_1 e^{\frac{k_2 - d}{k_1}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

Eq.(4) can be used to find the velocity of wetting front at any distance from the jar

The V-d relation of $Eq.(10)$ is represented in Figs.(9,10, and 11).

7. Velocity Factor

If it is assumed that the velocity of wetting front in the vadose zone is a function of the applied hydraulic head as $v \propto h$ and/or

$$v_{h_1} = \pounds\, v_{h_2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (11)$$

for a certain soil, Where:

v_{h_1} *is the velocity of wetting front under a hydraulic head* h_1, v_{h_2} *is the velocity of wetting front under a hydraulic head* h_2 *and* £ *is the velocity factor*. In Figs.(9, 10, and 11) if we assume that:

$v_{h_0} = k_{01} e^{\frac{k_{02} - d}{k_{01}}}$ and $v_{h_1} = k_{11} e^{\frac{k_{12} - d}{k_{11}}}$ substitute in Eq.(11) to obtain:

$$\pounds = \frac{k_{01}}{k_{11}} e^{\frac{k_{02} - d}{k_{01}} - \frac{k_{12} - d}{k_{11}}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (12)$$

Where k_{01} and k_{02} are the coefficients of clay, sand, and mixture soils fit functions respectively under the hydraulic head h=0m of Figs.(6, 7, and 8) and k_{11} and k_{12} are the coefficients of clay, sand and mixture soils under the hydraulic head h=1.25m fit functions of Figs.(6, 7, and 8). Since the coefficients $k_{01,}\ k_{02}, and\ \ k_{11},\ k_{12}$of Eq.(11) are constant for each hydraulic head h=0m and h=1.25m respectively, then the velocity factor £ is a function of the distance d from the jar walls. Fig.(12, 13 and 14) shows the values of £-d relation.

8. Results Analysis and Issues

The laboratorial results lead to the following issues:-

1- Fig.(6) presents that the maximum distance reaches by the wetting front is approximately 30cm which means that the maximum spacing between two adjacent jarrahs is 60cm in clayey soil.

2- Similarly, from Fig.(7 & 8), the maximum spacing between adjacent jarrahs is 30cm in Sandy and mixture soil.

9. Characteristics of HOPIS

This method could be used in the following circumstances

1- This type of irrigation is cheap and easy to setup.

2- It works with transplants or direct seeding, and improves seed germination and stability even in hot and dry conditions.

3- It is characterized with tremendous efficiency of the delivery of the fertilizer directly to the plant's roots.

4- Since irrigated water is not powered on soil surface, soil structure stays loose near seedbed to enable water and air circulation through.

5- It could be used for flat and rugged topographical lands.

6- It could be used for all types of vegetation and orchards.

7- It is effective in saving water consumption (one-third of the conventional methods of irrigation).

8- The whole system can be made with locally available materials and skills.

9- Osmotic Jar can be used several times after cleaning the sediments of suspended materials and salinity calcinations.

10- Plastic pipes and Osmotic Jar covers characterized with long durability life if they are buried.

11- All parts of the HOPIS can be produced by manufacturing factories and\or by common skill of farmers.
12- Several seasonal farming can be used for one HOPIS setup.

10. HOPIS Setup and Operation

Standard setup of HOPIS is started with the setup of osmotic jars. The farmer primarily distributes the osmotic jars over the farm area as a grid system and the distance in between grids depending on plant type and buried them below ground surface (only 2cm of jar neck is let to be above soil surface) as a grid system and then the osmotic jars should be connected to transmission water pipes network which in turn is fed with water from water tank. After, the farmer has finished a seeding and planting process, he should open the main valve to start the irrigation process by HOPIS.

11. Conclusions

1- In this irrigable technology, experimental measurements prove that wetting front moves faster in clay soil that sandy and mixture soils. This is attributed to osmotic (negative) pressure outside the jars that it is too active in clay soil than other soil types.
2- The £-d relation is linear for clayey soils whereas it is non-linear for other soils; sand and mixture.
3- The consuming water is found to be higher in clayey soils than other soils.

12. Recommendation

It is recommended to estimate the average water consumption of clayey jars for different soil types (clay, sand, and loam soils) under different hydraulic heads.

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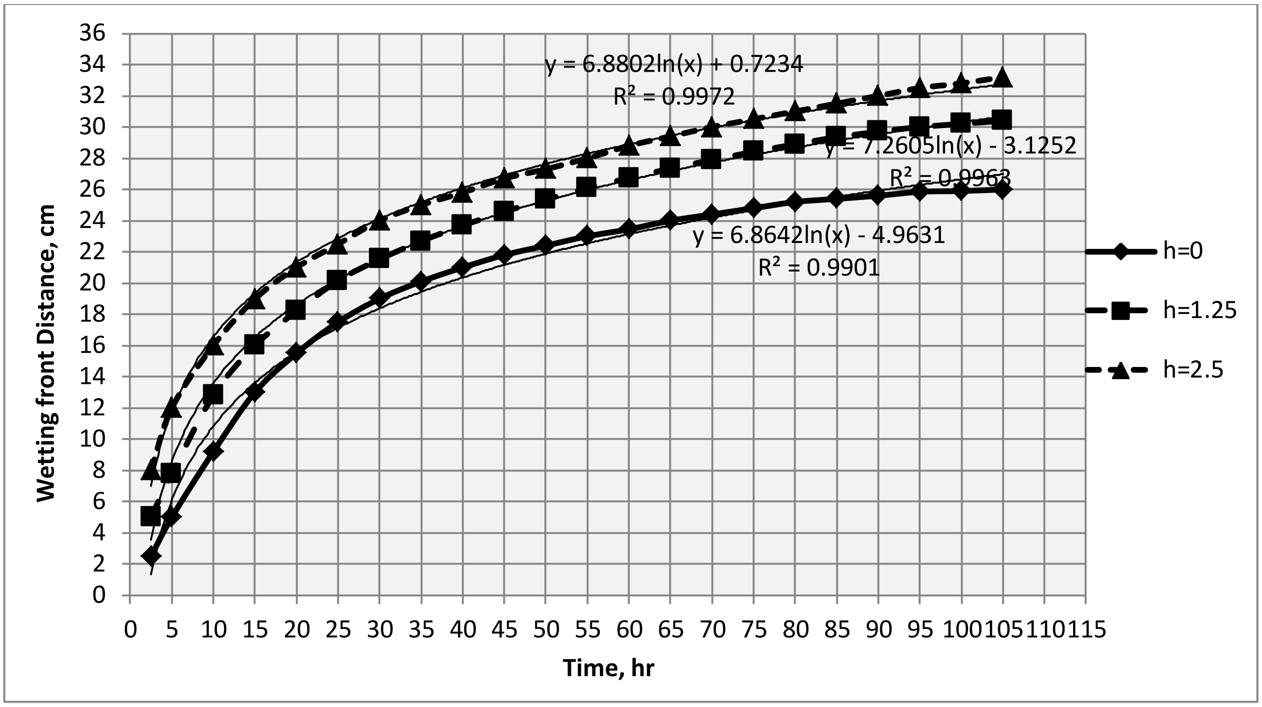

Fig.(6) Time-Distance Relation of Wetting front Advance with different hydraulic Heads in Clay Soil

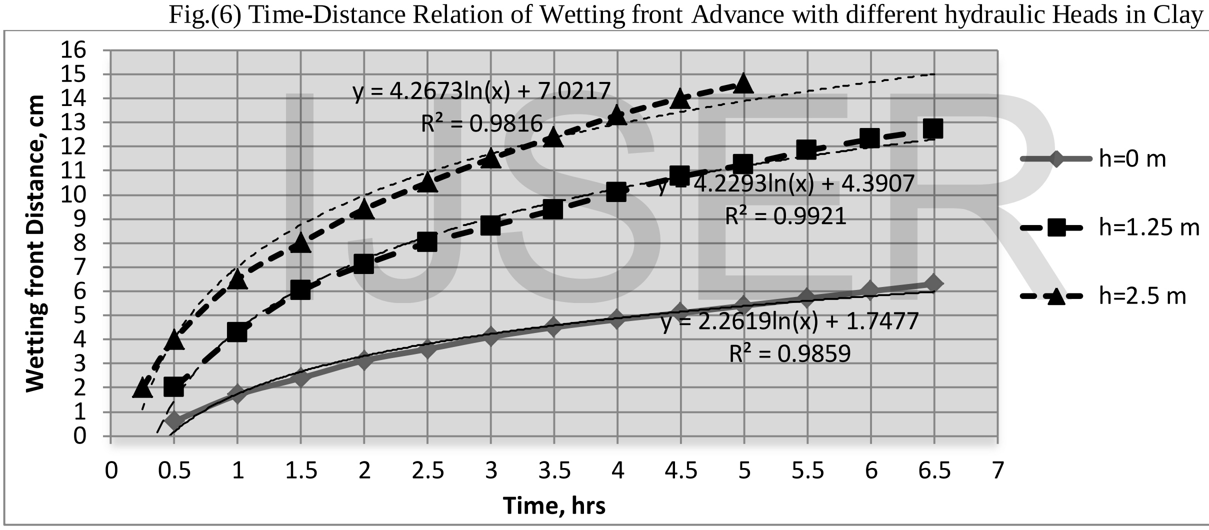

Fig.(7) Time-Distance of Wetting front Advance under Different Hydraulic Heads in a Sandy Soil

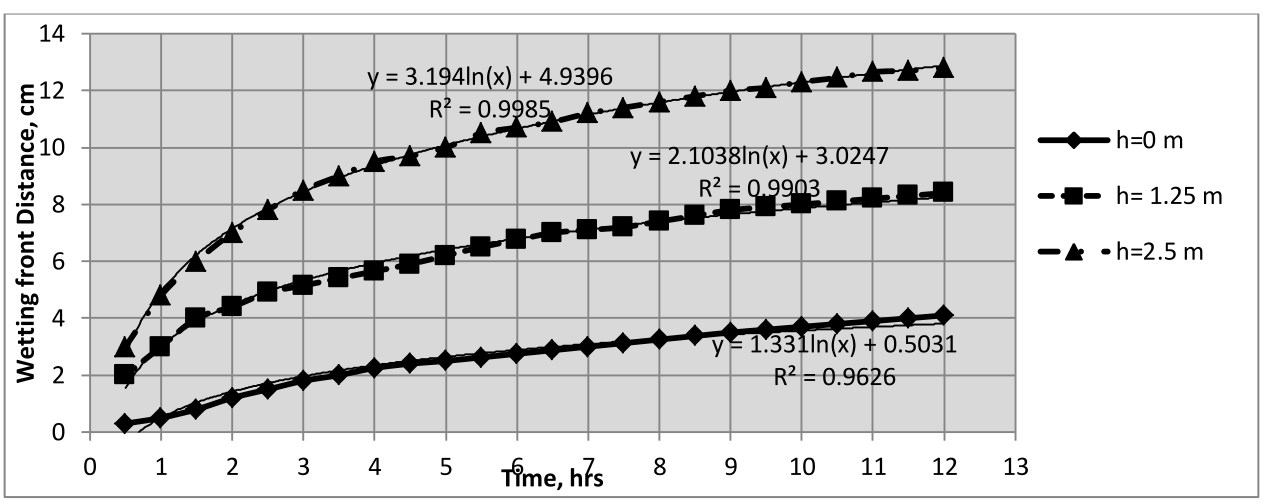

Fig.(8) Time-Distance of Wetting front Advance under Different Hydraulic Heads in Clay-Sand- Fertilizer Soil

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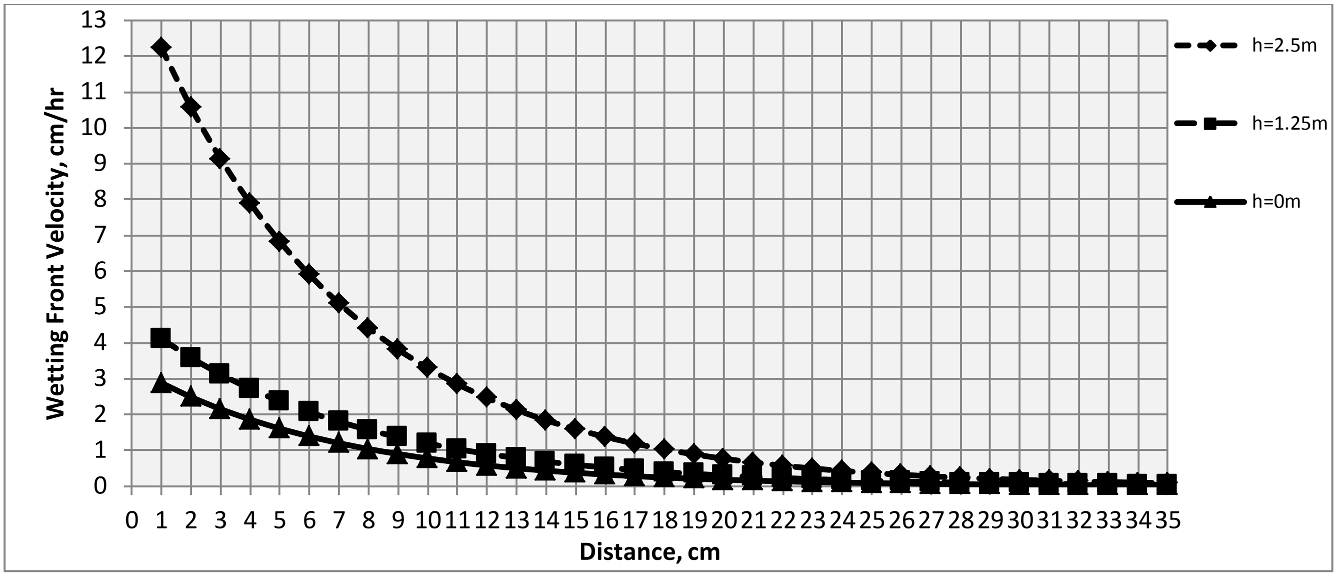

Fig.(9) Velocity-Distance Relation of Wetting front Advance in a Clayey Soil

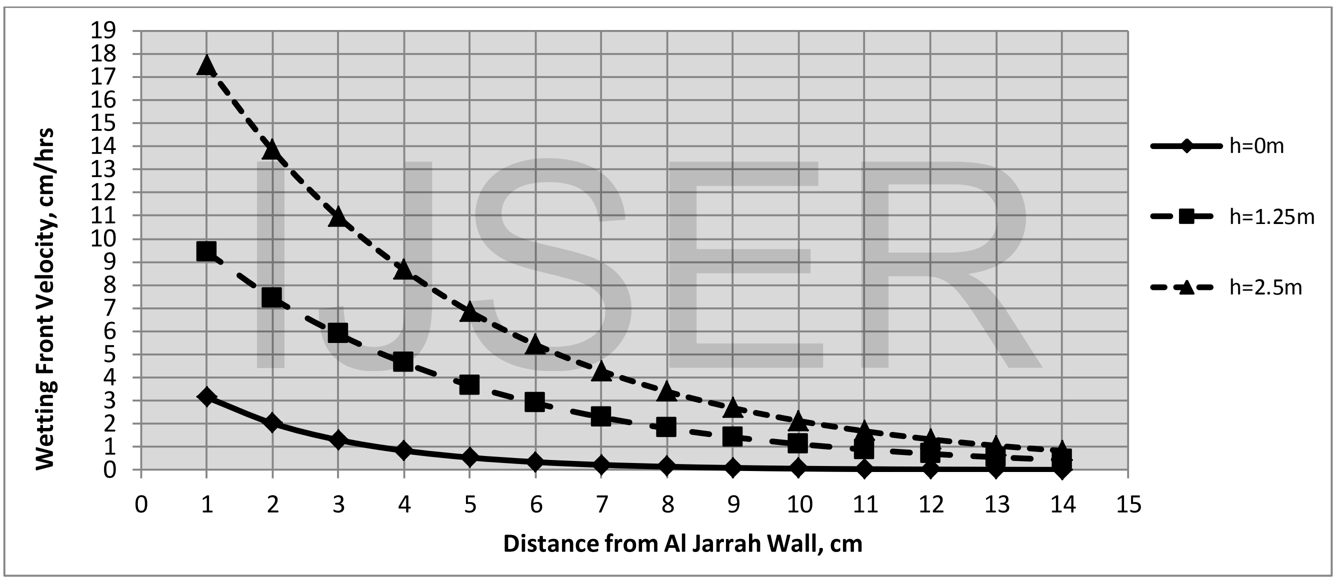

Fig.(10) Velocity-Distance Relation of Wetting front Advance in a Sandy Soil

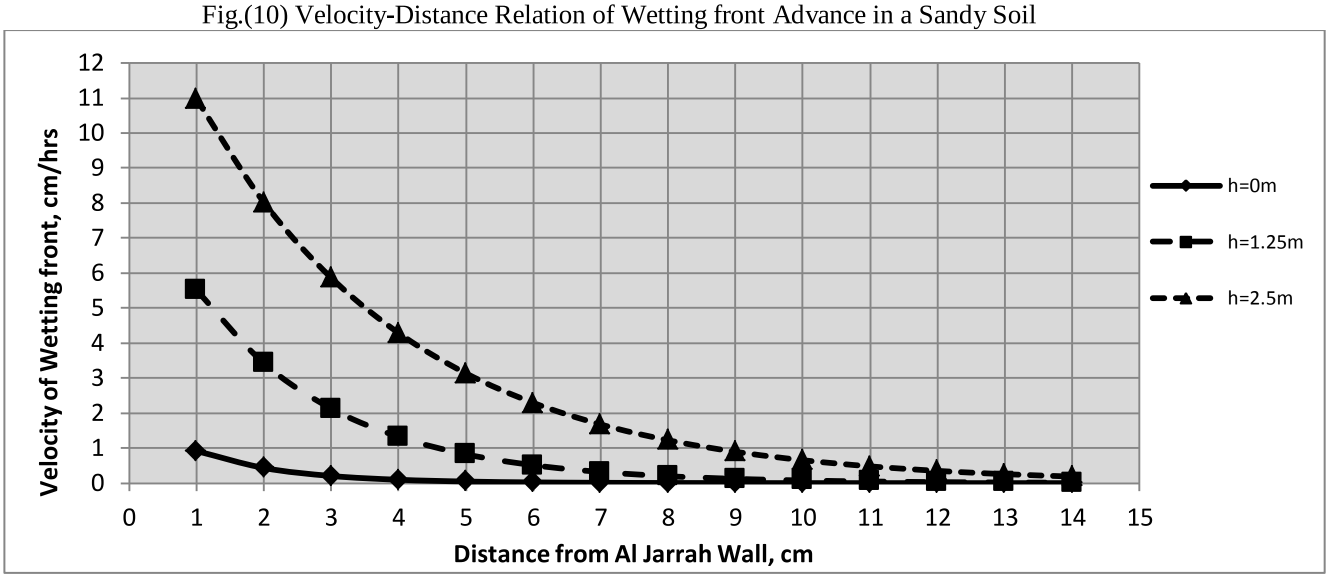

Fig.(11) Velocity-Distance Relation of Wetting front Advance in Sand-Clay-Fertilizer Soil

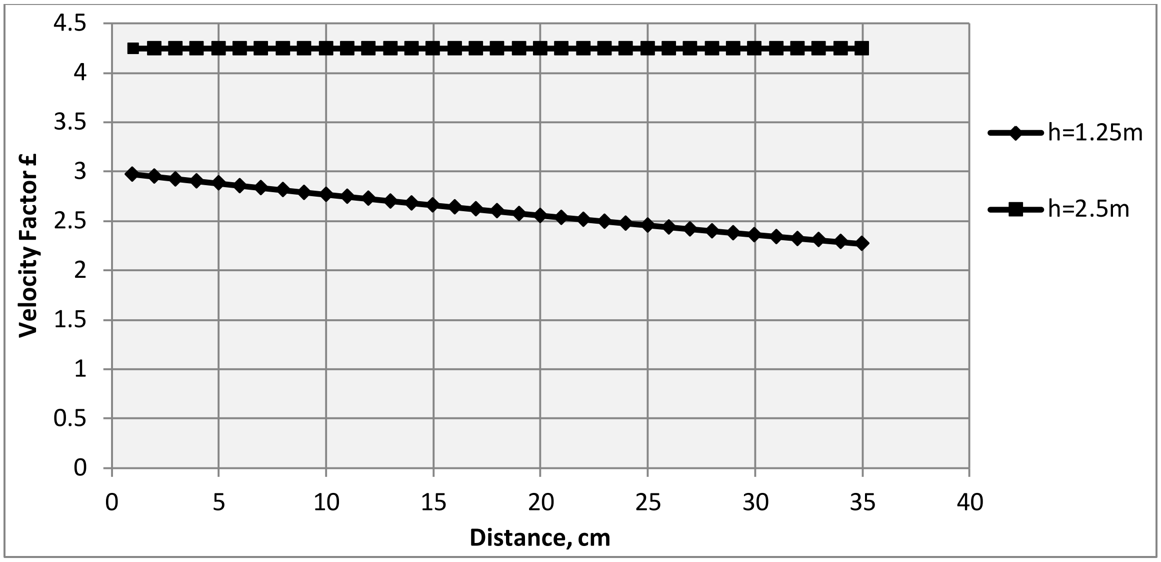

Fig.(12) Velocity Factor of Clay Soil

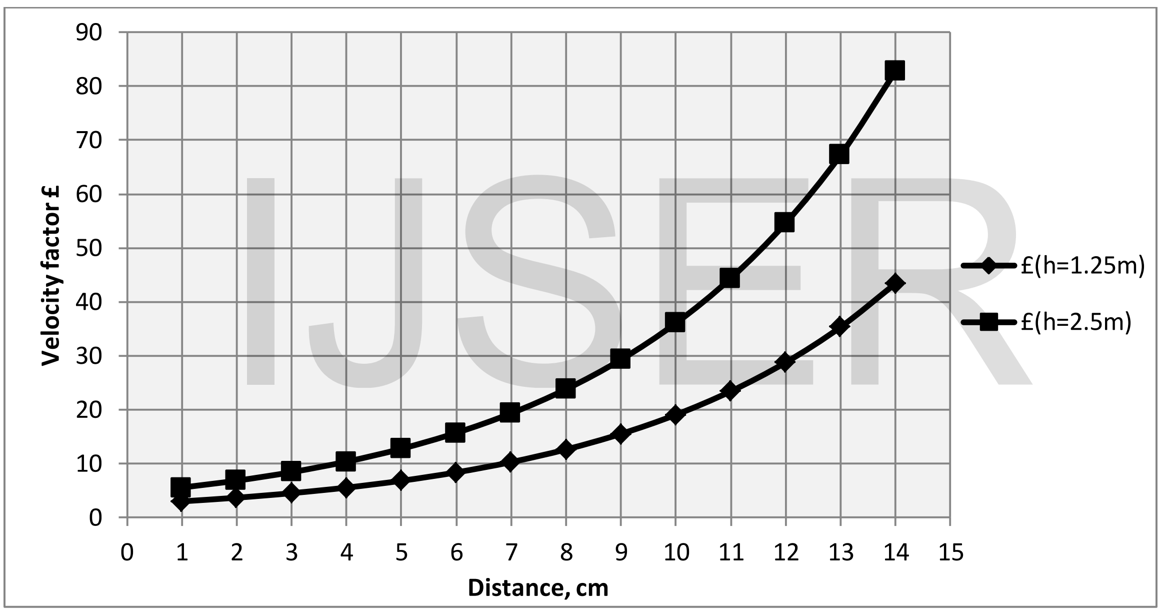

Fig.(13) Velocity Factor for sandy soil

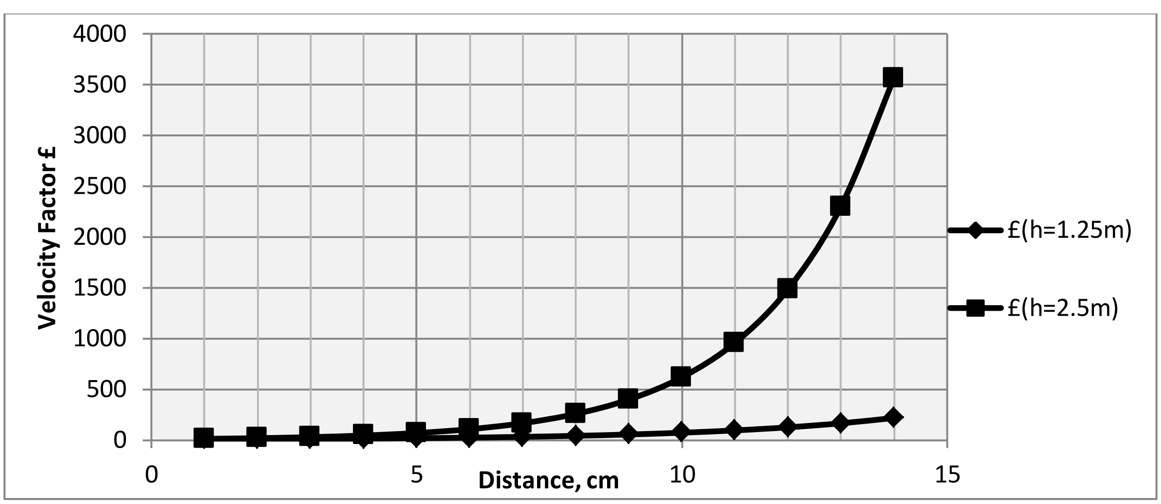

Fig.(14) Velocity Factor for Mixture Soil