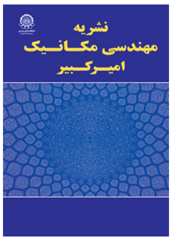

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Simulation and Optimal Design of Solar Pool for Subsurface Irrigation

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ABSTRACT: Nowadays, according to the pollution and reduction of available water resources, accessing to fresh water for agricultural and drinking purposes are restricted. In this paper, the solar subsurface irrigation system, which is one of the most efficient ways of fresh water production has been simulated. This system consists of a pool as a humidification unit and pipes that are buried in the soil as a condenser unit. In this simulation eight parameters including relative humidity, water pool temperature, pressure, pipe temperature, inlet air cross section, air temperature, air velocity and pipe diameter have been considered in three levels and 27 tests to calculate the amount of fresh water were presented using Taguchi method. In order to maximum use of sunlight, the mirror was used. The results showed that the lower humidity, pipe temperature, velocity and inlet air cross section increase the amount of water production. In addition, the higher pipe diameter, water temperature and air temperature is directly proportional to the amount of produced water. The optimal pressure is 95 kPa. The optimal amount of fresh water obtained from Taguchi method is 5.15 kg/m.day which shows an error of 5.23% compared to simulation result.

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1- Introduction

Rapid population and industry growth in the world, has increased the need for fresh and healthy water for drinking and farming but on the other hand the pollution of water resources by industrial and municipal effluent causes a shortage of safe water resources. Investigators are looking for ways to access fresh water from sea water and salt water, with less energy and cost. One of the most efficient methods is subsurface irrigation using a humidification-dehumidification process that provides salt water for irrigation and drinking. Ayras et al. [1] in 2015 examined a subsurface irrigation system in agricultural production sector in California. Their results showed that the subsurface irrigation system has significant advantages in increasing performance, product quality, reducing irrigation and crop costs for weed and pesticides, control compared to other irrigation methods.

Okati et al. [2] in 2016 Studied a humidification-dehumidification desalination for subsurface irrigation and fresh water. The results of their research showed that the optimum amount of water generated per meter of tube is 3.81 kg/m.day.

2- Solar Subsurface Irrigation System

Solar subsurface irrigation system is a combination system for irrigation and fresh water production. This system due to the use of renewable energy of the sun and also the use of salt water and non-drinkable water has been very effective. The only basic cost is related to build the system and its energy source is the sun that available for free and always available and economically is viable. This system consists of a pool of 10 m×10 m as a unit of humidity that by passing air flow from the pool water surface, the air becomes warm and humid. Also, the buried pipe in the ground is a condensing unit. Hot and humid air at the end of the pool enters the pipe and due to heat transfer and the loss of heat, fresh water is produced. Subsurface irrigation was first introduced in California in 1980 [3]. The schematic of the solar subsurface irrigation system is shown in Fig. 1.

Considering the air inside the pool as a control volume:

$$C_{pa}(T_O - T_i) + \omega_o h_{vo} - \omega_i h_{vi} = \frac{1}{\dot{m}_a}(Q_{cw} + Q_{ew}) \tag{1}$$

$$\omega_o = \omega_o + \frac{g_s}{\dot{m}_a} \tag{2}$$

Fig. 1. Schematic of solar submarine irrigation system

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Table 1. Parameters and levels affecting the test

Number	parameter	Lev 1	Lev 2	Lev 3
1	Relative humidity (%)	20	50	80
2	Water temperature, °C	40	50	60
3	Pressure, kPa	95	100	105
4	Pipe temperature, °C	15	20	25
5	Input cross section, m^2	0.1	0.5	0.9
6	Air temperature °C	40	35	30
7	Pipe diameter, m	0.05	0.1	0.15
8	Air velocity, m/s	0.01	0.05	0.1

where ω, h (kj/kg), g_s (kg/s), m_a (kg/s), T (°C), Q_{ew} (W), and Q_{cw} (W) are humidity ratio, enthalpy, evaporated water mass, flow rate, temperature, heat of evaporation and heat of convection between the water surface and the surrounding area respectively. Using the Eqs.(1) and (2), the temperature and humidity of each element are calculated. In order to optimally use the sun's radiation, a mirrored screen is used to radiate more sunlight to the water inside the pool.

In the tube as a condenser, Eqs. (3) and (4) are established.

$$q_{cond} = Lh_m(\varphi\rho_{v,s}(T_a) - \rho_{v,s}(T_p)) \tag{3}$$

$$m_c = \pi D \Delta Z \frac{q_{cond}}{L} \tag{4}$$

where $\rho_{v,s}$ (kg/m^3), φ, L (J/kg), q_{cond} (W/m^2), m_c (kg) are saturation vapor density, relative humidity, latent heat of vaporization, condensed heat and condensed water respectively. From Eqs. (3) and (4), the amount of water condensed in the tube is obtained.

3- Results and Discussion

To optimize and evaluate the system used the Taguchi method by introducing the amount of water produced by introducing as the objective function. Design parameters are introduced at three different levels that is shown in Table 1. The Lev in Table 1 is the same level.

Taguchi method uses the design parameters and levels to introduce 27 tests. Each tests in MATLAB is simulated and calculated then the results come in MINITAB. The results of the tests are presented in Table 2.

According to the analysis, Taguchi recommends the best of each of the eight parameters examined in accordance with Table 3. The optimal amount of fresh water obtained from Taguchi method is 5.15 kg/m.day which shows an error of 5.23% compared to simulation result. The simulated amount with MATLAB was 5.43 kg/m.day.

Table 2. Test results

Test number	Mass of water (kg/m.day)
1	5.4348
2	2.79
3	0.7030
4	3.7212
5	0.89
6	1.6261
7	2.9133
8	3.8949
9	0.751
10	1.8573
11	0.3726
12	1.1636

Table 2. Test results - *Continue*

Test number	Mass of water (kg/m.day)
13	1.7226
14	0.7753
15	1.8770
16	1.5160
17	1.7076
18	1.852
19	1.1414
20	1.3883

Test number	Mass of water (kg/m.day)
21	0.9063
22	0.6770
23	1.9162
24	0.8477
25	1.6033
26	2.0926
27	1.1520

4- Conclusions

The higher temperature of the inlet air to the pool to cause the higher the amount of water generated On the other hand less relative humidity (20%) had the greatest impact on freshwater production so this irrigation method is suitable for hot and dry areas. The pipe diameter will increase, causing more water to be produced also the lower pipe temperature, velocity and inlet air cross section increase the amount of water production. The higher water temperature inside the pool increases the amount of water produced. Due to the renewable and the availability of wind and solar energy, this method is very economical and the cost of launching it is much less than the cost of drilling and piping for the transfer of freshwater to arid and remote desert areas.

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Table 3. Best status introduced by MINITAB

Number	Parameter	Optimal level	Amount of level
1	Relative humidity (%)	1	20
2	Water temperature, °C	3	60
3	Pressure, kPa	1	95
4	Pipe temperature, °C	1	15
5	Input cross section m^2	1	0.1
6	Air temperature, °C	1	40
7	Pipe diameter, m	1	0.05
8	Air velocity, m/s	1	0.01

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