Laboratory scale experimental study to investigate the impact of soil moisture content on the performance of earth air heat exchanger for summer cooling

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***Abstract* - Earth air heat exchanger uses the nearly constant temperature of sub-soil to provide space cooling in summer. Due to the thermal saturation of sub-soil around the heat exchanger pipe, it's performance decreases in the long run. Increase in soil moisture content is known to improve the thermal properties of soil and thus enhances the performance of EAHE. In this study, impact of soil moisture content on the performance of EAHE has been investigated experimentally, using laboratory scale setup, for summer cooling. The experimental setup has been developed inside a room of dimension 3m × 3m × 3m in the Government Engineering College, Ajmer, India. Results show that the temperature drop of air in dry soil, after six hours of operation, is 9.4 °C, whereas in wet soil with 5%, 10%, 15% & 20% moisture content, the temperature drop is 10.1 °C, 10.8 °C, 11.4 °C & 11.8 °C respectively.**

Keywords: Earth Air Heat Exchanger, Summer Cooling, Thermal Saturation, Soil Moisture Content.

I. INTRODUCTION

One of the largest energy consumers in the world is the building sector. Present building energy demands of space cooling and heating are fulfilled by the conventional HVAC systems. To improve the energy balance of buildings, we can opt for the local, renewable energy sources. Geothermal energy is one of the several renewable resources that can be used throughout the year in a constant and durable way. During the summer season, for the cooling load reduction in the buildings, it can be considered as an ideal solution. Earth–air heat exchanger (EAHE) system is an example of a passive system which uses geothermal energy to provide space cooling and heating effects in summer and winter respectively.

The ground temperature, at a depth of a few meters below ground level (3-4 m), remains approximately constant throughout the year [1]. EAHE system uses that nearly constant temperature of sub-soil to provide space cooling in summer and heating in winter. An EAHE system consists of a pipe buried in the ground, through which the air passes to be cooled in summer months and heated in winter months [2]–[4]. These systems have their advantages of energy savings and much lesser CO_2 emissions. But due to the thermal saturation of sub-soil around the heat exchanger pipe, their performance decreases in the long run [5]. The performance of EAHE system significantly depends on the thermal properties of the sub-soil. Improvement in these soil thermal properties is required to enhance the thermal performance of the EAHE system.

Soil thermal conductivity is a significant parameter on which the heat transfer between the EAHE pipe and soil depends. Increase in the moisture content of soil results in the increase of soil thermal conductivity value and other thermal properties of soil [6]–[9]. Thus, high amount of moisture in the sub-soil can have the positive effect on the performance of EAHE system [10], [11]. Many researchers have also provided the mathematical models to explain the coupled process of heat and moisture transfer in the sub-soil which helps in the better thermal performance of EAHE system [12]–[15].

In the present study, impact of soil moisture content on the performance of an EAHE system has been investigated experimentally, using laboratory scale setup, for summer cooling. The experimental setup has been developed inside a room of dimension 3m × 3m × 3m in the Government Engineering College, Ajmer, India. Thermal performance of EAHE system has been analyzed on the basis of air temperature drop along the length of pipe.

II. DESCRIPTION OF LABORATORY SCALE EXPERIMENTAL SETUP

Experimental setup was consisted of two identical soil containers of dimension 2.4m × 0.46m × 0.46m each. Both the soil containers were filled with local Ajmer soil, and one steel pipe (inner diameter 0.025 m and length 2.5 m) was provided at the center of each container (as shown in Fig. 1). Soil in one container was kept dry and the moisture content of soil in the other container was changed after every two days (Fig. 2). The laboratory scale earth-air heat exchanger setup was installed inside a room of dimension of 3m × 3m × 3m in the Mechanical Workshop of Government Engineering College, Ajmer, India. Thermal performance of the wet EAHE system with 5%, 10%, 15% and 20% moisture content has been experimentally investigated for summer cooling, and compared with the dry EAHE system.

Steel pipe of inner diameter 0.025m and length 2.5 m was provided at the center of each container and air was made to pass through both these pipes simultaneously. A centrifugal blower (make: Captain, power: 750 W, speed: 2800 rpm) was used to blow the ambient air through the pipes and the speed of the blower was changed by regulating voltage using an auto-transformer. A hot wire anemometer (make: Lutron, model: AM 4204, velocity: 0-20 m/s, resolution: 0.1 m/s) was used to measure the velocity of air flowing through the EAHE pipe. An air-heater was installed after the blower to provide the air at constant temperature to the system. Air heater consisted of a box made of steel in which an electrical heating coil of 1500 watts was placed to heat the ambient air. Variac was used to control the air temperature by regulating the voltage. Fine holes were drilled on the pipes to insert temperature sensors up to the centre of the pipes. Five resistance temperature detectors (RTDs, Pt-100 sensors, IST make) were mounted along the pipe length of each EAHE system at 0m, 0.6 m, 1.2 m, 1.8 m and 2.4 m respectively, from the inlet, to measure air temperatures as shown in Fig. 1. RTD temperature sensors were also installed in the soil at different locations, in both the soil containers, to measure the soil temperature variation with time. To record the temperature data on hourly basis, all the RTD sensors were connected to a data-logger (make: Key sight technologies, model: Agilent 34972A). Also, nine Water-Mark moisture sensors were employed in the wet EAHE system to measure the moisture content of soil.

Fig. 1 Identical soil containers for the experiment

Fig. 2 Piping arrangement for the addition of moisture in soil

III. EXPERIMENTAL PROCEDURE AND MEASUREMENT

The laboratory scale setup was chosen to analyze the thermal performance of dry and wet EAHE system under controlled conditions. Both systems were operated simultaneously with considering 5%, 10%, 15% and 20% moisture content for wet system. Initially, the soil in both the containers was kept at 26 °C, representing the ground temperature of Ajmer, India at 3-4 m depth below the ground surface. The temperature of the room in which the experiment was performed was also kept at 26 °C during the course of the experiment to provide actual ground conditions to the EAHE pipes. Water was supplied to the wet system with the help of a piping arrangement to uniformly distribute the moisture in the soil. Everyday water was supplied about 4 hours

Fig. 3 Centrifugal blower and Air-heater

prior to the start of the experiment, so that enough time is available for water to get distributed uniformly in the soil around the EAHE pipe. From 11 am to 5 pm, both the systems were operated simultaneously and then both dry and wet EAHE systems remained off till 11 am of subsequent day so that the soil gets regenerated. Using centrifugal blower and air heater, ambient air was supplied through the EAHE pipes at an inlet temperature of 43 °C and flow velocity of 10 m/s.

Experimental study was performed in the month of January, 2019. The measurements were taken for two days each for every moisture content considered. Values of air temperature along the length of pipe for the dry EAHE system have been averaged for four days and they have been compared with air temperature values obtained for the wet EAHE system with 5%, 10%, 15% and 20% moisture content.

Table 1,2 and 3 presents the air temperature variation along the length of pipe after 1 hour, 3 hours and 6 hours of operation, at constant air flow velocity of 10 m/s, for both dry and wet EAHE systems with different moisture contents (i.e., 5%, 10% 15% and 20%).

IV. PERFORMANCE ANALYSIS OF WET AND DRY EAHE SYSTEM

Table 1, 2 and 3 show that the temperature drop of air along the pipe length for wet EAHE system with 20% moisture content is highest. Table 1 and Fig. 4 show that, after 1 hour of operation, total temperature drop of air along the length of pipe for

Table 1 Air temperature variation along pipe length for both dry and wet EAHE systems after 1 hour of operation

Section at pipe length (m)	Air Temperature (°C)				
	After 1 hour				
	Dry soil	Wet soil (Moisture Content)			
	Average of 4 days	5%	10%	15%	20%
0	43	43	43	43	43
0.6	38.8	38.3	37.9	37.6	37.4
1.2	35.3	34.7	34.2	33.9	33.7
1.8	32.9	32.2	31.6	31.3	31
2.4	31.3	30.5	30	29.6	29.4

the dry EAHE system is 11.7 °C whereas for the wet EAHE system with 5%, 10%, 15% and 20% moisture content, the total air temperature drop along the pipe length is 12.5 °C, 13 °C, 13.4 °C and 13.6 °C respectively.

Similarly, after 6 hours of operation, total temperature drop of air at the exit of the pipe, for the wet EAHE system with 5%, 10%, 15% and 20% moisture content, is 10.1 °C, 10.8 °C, 11.4 °C and 11.8 °C respectively as compared to a total air temperature drop of 9.4 °C for the dry system (Fig. 6). It can be seen that, for the same pipe length, 25.5% more air temperature drop has been obtained at the exit of the pipe for the wet EAHE system with

20% moisture content as compared to the dry EAHE system after 6 hours of operation.

Table 2 Air temperature variation along pipe length for both dry and wet EAHE systems after 3 hours of operation

Section at pipe length (m)	Air Temperature (°C) After 3 hours				
	Dry soil	Wet soil (Moisture Content)			
	Average of 4 days	5%	10%	15%	20%
0	43.0	43.0	43.0	43.0	43.0
0.6	39.3	39.0	38.6	38.3	38.1
1.2	36.3	35.8	35.4	34.9	34.6
1.8	34.0	33.4	32.8	32.3	32.0
2.4	32.4	31.7	31.0	30.5	30.2

Table 3 Air temperature variation along pipe length for both dry and wet EAHE systems after 6 hours of operation

Section at pipe length (m)	Air Temperature (°C) After 6 hours				
	Dry soil	Wet soil (Moisture Content)			
	Average of 4 days	5%	10%	15%	20%
0	43.0	43.0	43.0	43.0	43.0
0.6	39.8	39.5	39.2	38.8	38.5
1.2	37.2	36.6	35.9	35.5	35.1
1.8	35.1	34.5	33.7	33.2	32.7
2.4	33.6	32.9	32.2	31.6	31.2

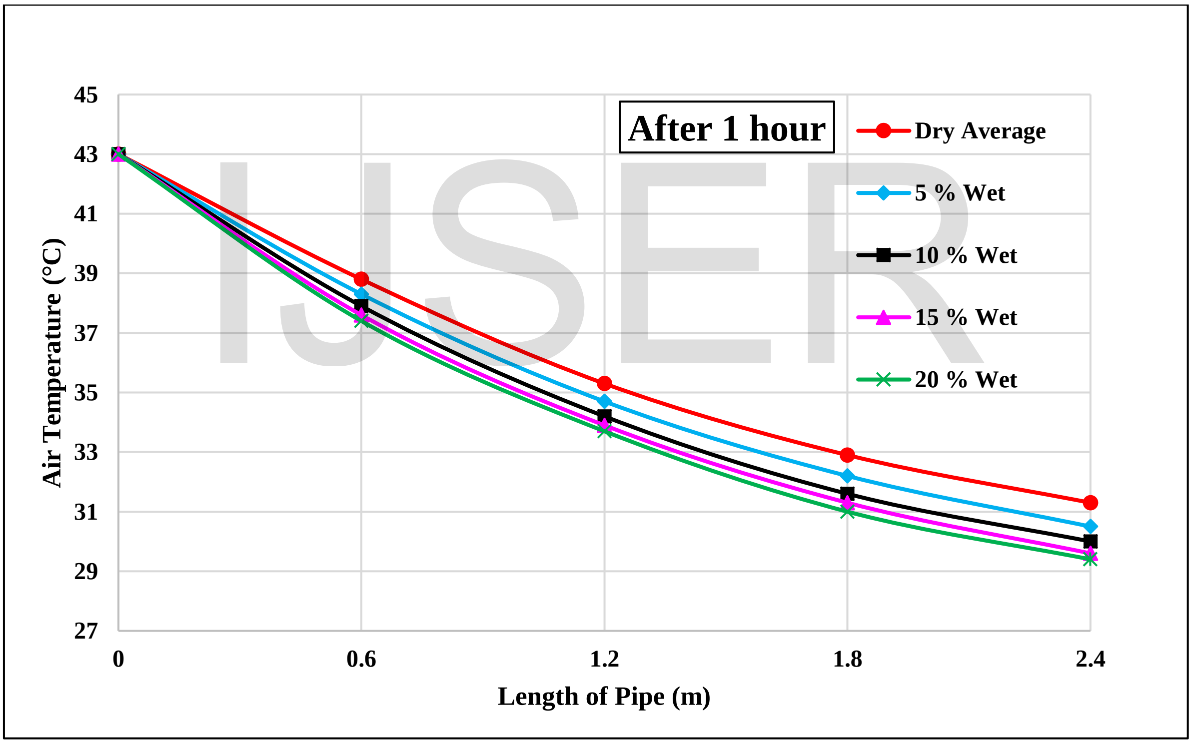

Fig. 4 Air temperature variation along the length of pipe for dry and wet EAHE system after 1 hour of operation

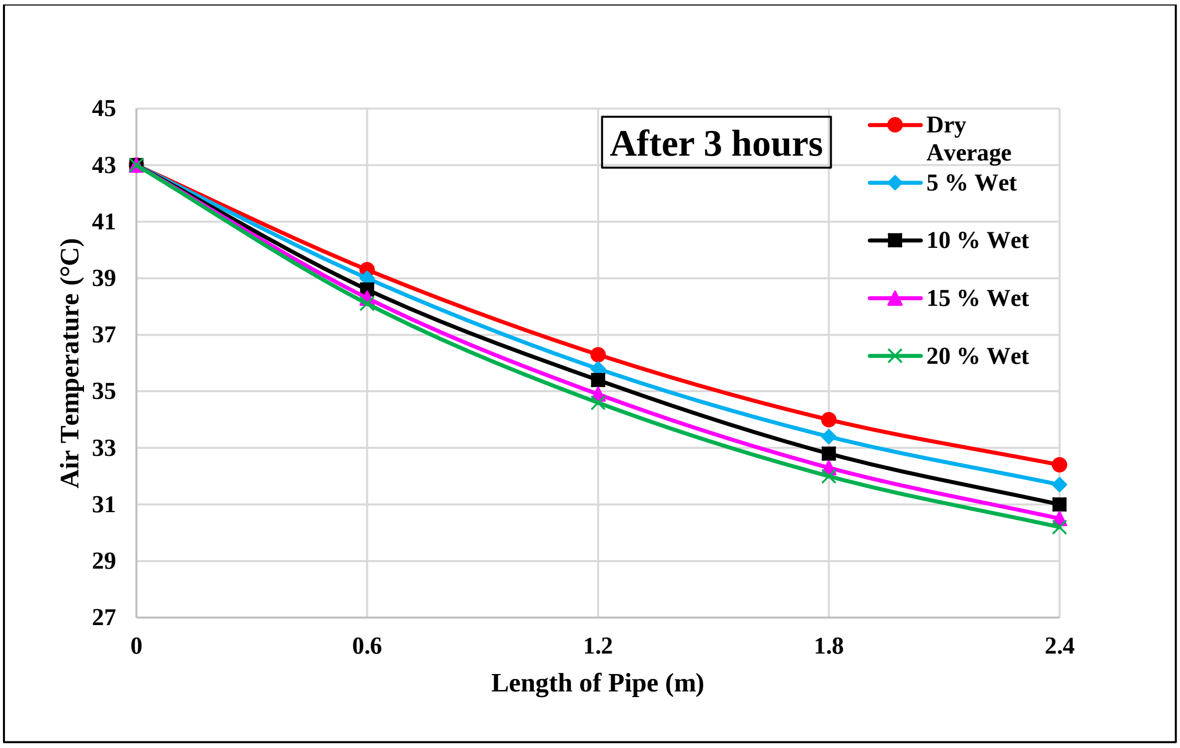

Fig. 5 Air temperature variation along the length of pipe for dry and wet EAHE system after 3 hours of operation

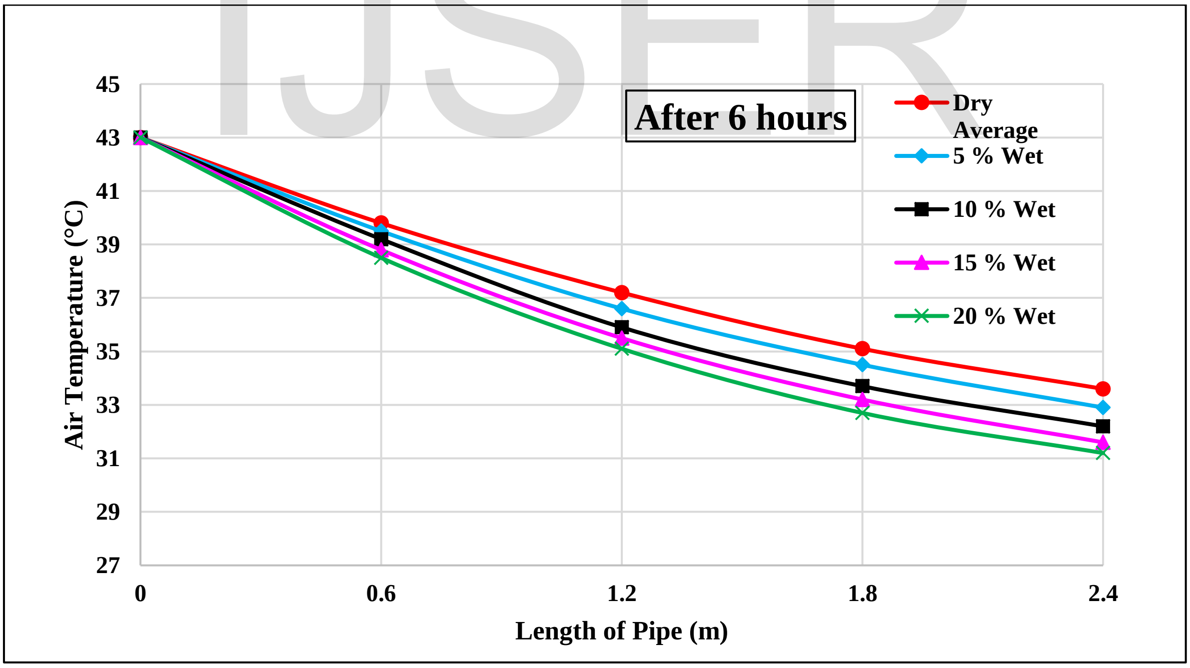

Fig. 6 Air temperature variation along the length of pipe for dry and wet EAHE system after 6 hours of operation

V. CONCLUSIONS

In this study, thermal performance of both the dry and wet EAHE systems has been investigated experimentally. Both the systems were operated simultaneously at a constant air velocity of 10 m/s from 11 am to 5 pm in the month of January, 2019 under controlled conditions. Thermal performance of EAHE system has been analyzed on the basis of air temperature drop along the length of pipe. Main observations of the study are:

1. After 6 hours of operation, air temperature drop along pipe length for the dry EAHE system was 9.4 °C. however, for the wet EAHE system with 5%, 10%, 15% and 20% moisture content, air temperature drop was 10.1 °C, 10.8 °C, 11.4 °C and 11.8 °C respectively.

2. Thermal performance of the wet EAHE system is better than the dry system, as more temperature drop of air has been obtained for the same pipe length.

3. The present study concludes that, increase in moisture content enhances the performance of EAHE system. Thus, high moisture content should be used in the soil near the heat exchanger pipe.

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