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12-2018

Controlling Relative Humidity Using Glycerin

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Project Summary

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Institution: University of Arkansas

Classification: Senior

Grade Point Average: 3.51/4.00

Area of Study: Civil Engineering (Geotechnical Emphasis)

Title of Project: Controlling Relative Humidity Using Glycerin

Abstract

A series of tests were conducted to control relative humidity (RH) using a bubbler system that contained a series of glass jars and glass vials filled with different concentrations of glycerin. The relative humidity within the glass jars was measured. The total time interval for each laboratory test was 48 hours. During the first 24 hours a pump was used to bubble air through the glycerin solution. During the second 24 hours, the pump was turned off, and the RH within the system was monitored within the closed system. Target RH measurements from 100% to a 0% were obtained. The factors that affected the RH measurements included the glycerin concentration and the air temperature within the bubbler system. Even subtle changes, such as going from 23° C to 22.8° C, resulted in a RH measurement increase between 5% to 10%. For example, when the target of RH was 100, the measured values stabilized at 95%. Likewise, when the target RH was 40%, the measured values stabilized at 33%. These changes occurred at a different rate over time. For example, at the 2 hours mark the target 100% RH was at 92% whereas at the 13 hours mark the target 100% RH was at 95%. Thus, a method was implemented to correct measurements of RH to 20° C, so these measurements could be more accurate to what the target values of RH (from 100% to 0%). This method included the back calculation of RH by using the absolute humidity (A) which is the ratio of the mass of water contained per volume of moist air. However, this method failed to correct the values as it increased the RH measurements by approximately 20%. Instead of correcting the values to 20° C, a new system was developed to control the system to 20° C ± 0.1° C.

Introduction

Three outputs including RH, room temperature, and critical temperature (temperature at which vapor of the mix cannot be liquefied) were obtained during a series of controlled tests. The procedure that was developed to obtain a given RH was divided into three stages, with improvements made between each stage. During the first stage, a closed-system with three glass jars, an air pump, a Vaisala RH and temperature probe, and a foam cooler was used. During the second stage, only two glass jars were used, and the Peltier cooling system was placed underneath the air pump. During the third stage, a water-pump and water-cooling block were included to allow for better control of the temperature in the system.

Although different levels of RH measurements were obtained by using different concentrations of glycerin, the aforementioned systems did not provide a consistent temperature-controlled environment. The lack of temperature control affected the effectiveness of the system to provide a consistent RH environment. Thus, a modified version of the system (continuation of the aforementioned Stage 3) is suggested as described herein.

Background

Relative Humidity (RH) is the ratio of the partial pressure of water vapor to the equilibrium pressure of water vapor at a given temperature (Bell, 2011). The temperature and the pressure within a system of interest affect the developed RH within the system. Due to correlations between RH and soil suction, controlling RH in a testing environment is a powerful method to control soil suction to determine the soil-water characteristic curve (Lu and Likos, 2004). Moreover, according to Ridley (2015), soil suction is an important parameter within geotechnical engineering because it can be used to study the stability of soils above the natural

water table. Thus, by knowing the soil suction within a soil mass, better foundation and earthwork design can be accomplished.

Houston et al. (1994) used a filter paper technique to determine the RH in soil samples. Houston et al. (1994), used various salt solutions to create a given RH level to subject filter papers to determine the RH level in the filter papers as a function of water content in the filter paper. Houston et al. (1994) then used the water content of filter paper in contact with the soil to determine suction of the soil and the soil water characteristic curve (swcc). Instead of using corrosive and dangerous salt solutions like Houston et al. (1994), Braun and Braun (1958), and Forney and Brandl (1992) used glycerin solutions to control RH.

As shown in Figure 1, Forney and Brandl (1992) tested different methods to determine the relationship between glycerin-water concentrations and RH level. Braun and Braun (1958) found that by changing the ratios of glycerin and water in a solution and by making correlations between specific gravity (SG) of the solution and RH values, RH values that were accurate to within one percent RH were obtained. Forney and Brandl (1992) also investigated how to control humidity in small enclosed glass jars using glycerin-water solutions. As documented by Forney and Brandl (1992), this method was advantageous for RH control because different glycerin and water ratios produced RH values that ranged from 0% to a 100%.
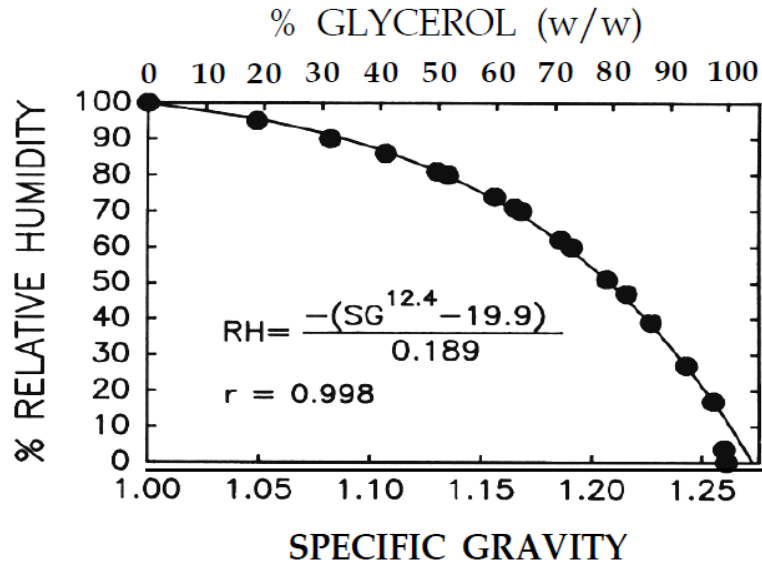
Figure 1. Relationship between the specific gravity (SG) of the glycerin solution and relative humidity (RH) at 24° C (from Forney and Brandl, 1992).

Methods and Procedures

The methods and procedures for measuring RH by changing the ratio of water to glycerin are presented in this section. Specifically, the closed-control system (pumps, glass jars, and cooler), and the testing procedures are presented. Moreover, developments and refinements to the testing procedure are also described for completeness.

The laboratory investigation that is described herein was completed using a bubbler system to consistently develop different levels of RH by using different ratios of water to glycerin. An air pump bubbled air into the glass vials that contained the glycerin-water solutions that were placed within larger glass jars. The air was distributed through the vials using fish tank bubble diffusers. A Vaisala model HMP110 was used to measure the temperature and RH level in the last glass jar in the sequence (Figure 2).

The specific gravity (SG) values of the glycerin-water solutions were computed by modifying the relationships developed by Braun and Braun (1958) and Forney and Brandl (1992).

RH >17% → SG = [-0.189(RH) + 19.9]$^{0.0806}$ Equation 1 (modified from Forney and Brandl, 1992)

RH ≤ 17% → SG = 0.0024(21.442-RH)$^{0.5}$ + 520.345   Equation 2 (modified from Forney and Brandl, 1992)

Equations 1 and 2 were used to compute the specific gravity values over a range of RH from 0% to 100%. Using the curve developed by Braun and Braun (1958), Equation 3 was created.

G_w = 383 (SG) – 383   Equation 3 (Braun and Braun, 1958)

Where G_w is the percent glycerin by weight, SG is the specific gravity, and RH is the relative humidity.

Using the SG value at every RH value, the percent glycerin by weight to produce a given RH level was calculated. After the SG values were determined, the mass of glycerin and mass of water were calculated. The results are summarized in Table 1.

Table 1. Relationships, ratios, and quantities of glycerin and water obtained by using the equations and relationship created by Braun and Braun (1954) and Forney and Brandl (1992).

Relative Humidity	Specific Gravity Glycerin-Water Solution	Percent Glycerin by Weight	Volume of Glycerin	Volume of Water	Mass of Glycerin	Mass of Water
RH	SG	G_w	G_v	H_v	W_G	W_W
[%]		[%$C_3H_8O_3$]	[ml]	[ml]	[g]	[g]
0	1.261	99.94	59.39	0.05	74.95	0.05
10	1.258	98.792	58.71	0.91	74.09	0.91
17	1.255	97.593	58.01	1.79	73.21	1.79
20	1.251	96.255	57.20	2.81	72.19	2.81
30	1.239	91.460	54.35	6.41	68.59	6.41
40	1.225	86.038	51.13	10.48	64.53	10.47
50	1.208	79.792	47.42	15.17	59.84	15.16
60	1.189	72.405	43.03	20.72	54.30	20.70
70	1.165	63.335	37.64	27.53	47.50	27.50
80	1.134	51.502	30.61	36.41	38.63	36.37
90	1.089	34.223	20.34	49.39	25.67	49.33
100	1.000	0.000	0.00	75.08	0.00	75.00

Closed-Control System

The closed-control system that was utilized to control the RH level went through two upgrades during the testing. The original testing device consisted of three medium size plastic jars, four large glass jars, a set of three fish tank bubble diffusers, tubing, an RH Vaisala measurement device, and an air pump (Figure 2). The set up allowed for creation of RH values from 0% to 100%. The first upgrade included the addition of a Peltier cooler, the reduction from four larger glass jars to three large glass jars, a reduction from three medium sized plastic glass jars to two small glass vials, and an automated RH data collector (Figures 3). The final upgrade included the addition of an active liquid cooling system. This system had a water pump, a plastic container with water inside in which the glass jars were placed, and a water-cooling block (Figure 4).
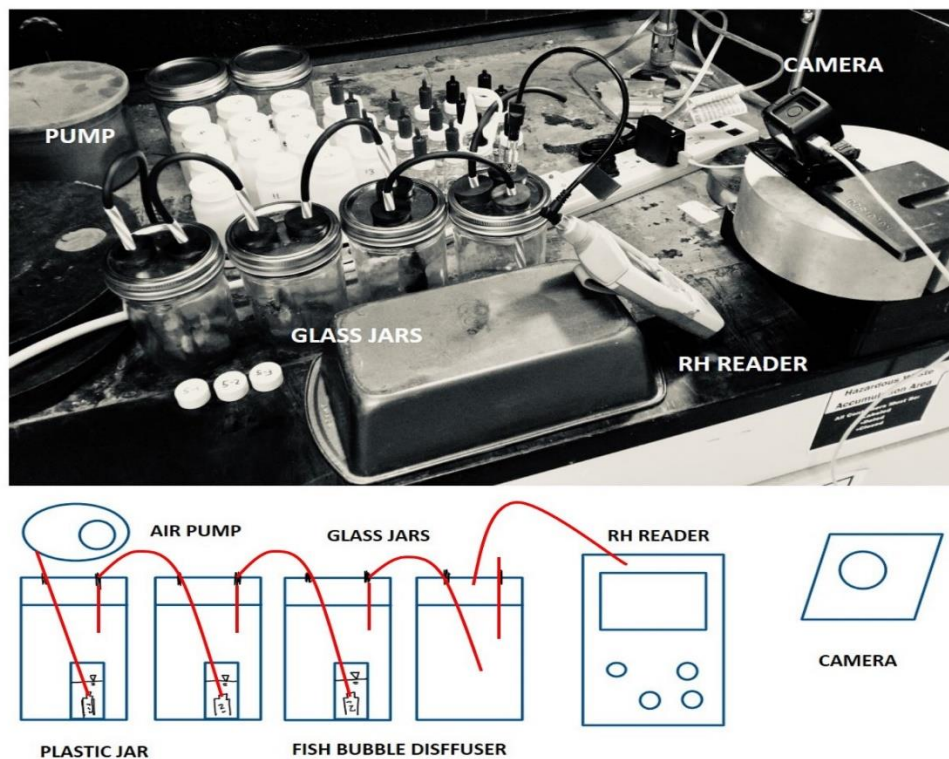

Figure 2. The original testing device consisted of three medium size plastic jars, four large glass jars, a set of three fish tank bubbled diffusers, tubing, an RH Vaisala measurement device, and an air pump.

In the original set up that included the four glass jars, the RH values were obtained by reading the RH values from the screen of the Vaisala handheld device by means of time-lapse photography acquired by a camera. The camera took photographs of the screen every one-minute for a 24-hour period. The air pump was used to pump air into the system. The system of jars was all connected by a tubing network that started at the air pump and ended at the exit of the foam cooler.

In the first upgrade, a Peltier cooler was located below the air pump, thus the air coming into the pump was cooled. Additionally, both the large glass jars and medium glass jars that were utilized in the first upgrade were reduced to smaller sizes, respectively. In the final upgrade, an active liquid cooling system was created by connecting a tubing system with the water pump and a water-cooling block. The active liquid cooling system was utilized to cool the water inside a plastic container that was located within the form cooler. All of the testing was performed within the same foam cooler.
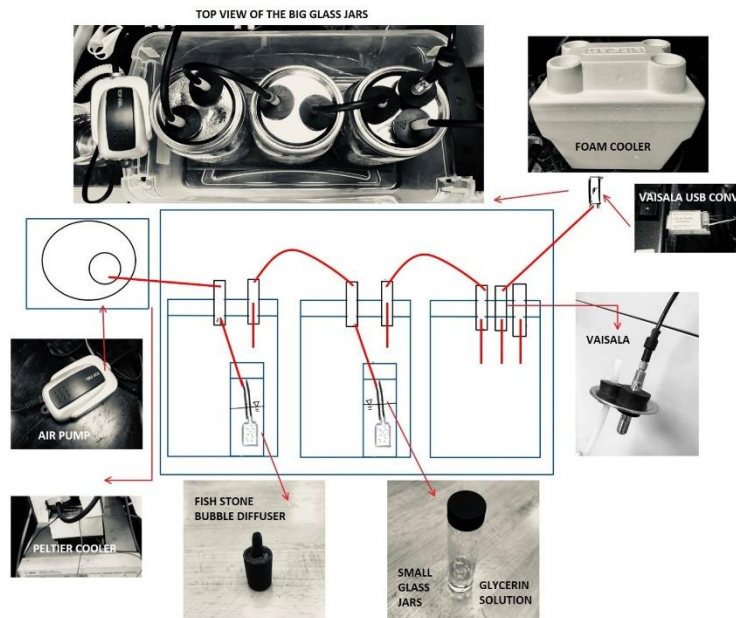

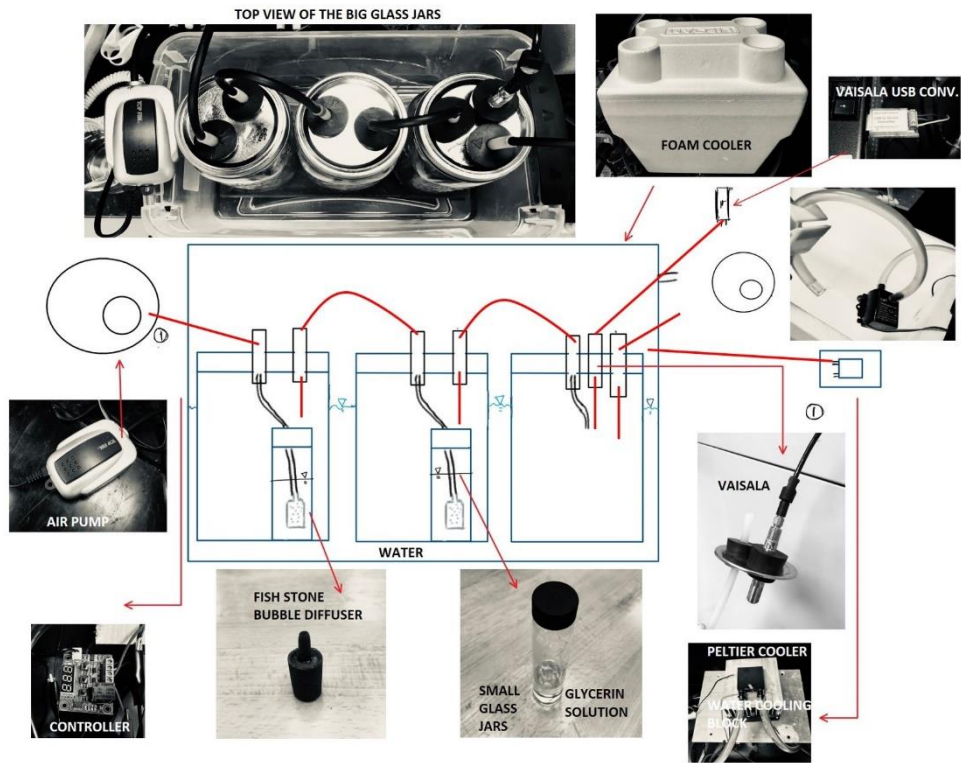Figure *3*. Set up use to collect RH values after the first upgrade.

Figure 4. Final suggested upgrade included the addition of an active liquid cooling system.

Testing Procedure

The testing procedure started with preparing each small vial. Each sample was made by using the target amounts of water and glycerin that were reported in Table 1. Each vial was filled with the required amount of water first and then the required amount of glycerin was added. In the first set up, a total of 75.0 g was used for the total sample. After preparation, the vials were placed inside the large glass jars. The solutions inside of the vials were stirred for one minute with the bubble diffuser to ensure that the solutions had a homogenous concentration inside the vial. Two kinds of tubing were used to connect all of the glass jars. The first was a clear solid tube where the fish tank bubbled diffusers stone diffusers were connected to. The second was a black soft tubing that was used to connect the air pump, the large glass jars, and the pump.

After the samples were placed inside of the large glass jars then the glass jar lids were sealed, and the pump was turned on. Every sample had a testing period of 48 hours where readings were taken every minute. During the first 24 hours the pump was on; during the second 24 hours the pump off. The outputs from the RH Vaisala probe included air temperature, critical temperature, RH, and time. The target concentrations led to RH measurements from 0% to 100%. After the first revision, the camera was removed, and measurements from the Vaisala probe were obtained using an analog to digital convertor, and the outputs were saved as a .txt file.

RESULTS

After the data were analyzed, two master plots were created. One plot (Figure 5) is the master plot for when the air pump was turned on. The other plot (Figure 6) is the master plot for when the air pump was turned off and the system was closed. Every plot includes eleven data sets covering the target RH range from 0% to 100%. As the room temperature increased, the RH values also increased. The constant changes in room temperature caused the measured values to differ from the initial target RH values.

After the pump was turned off, the inside temperature increased at a faster pace than when the pump was on, causing the RH to increase. Because of these sudden changes in temperature, the measurements of RH were not within the expected range. It appears that all the RH values tried to approach equilibrium with the RH level outside of the cooler. The RH level outside of the cooler was not measured. Measurement of the RH level outside of the cooler is suggested as it appears the outside RH level may affect the internal RH level.
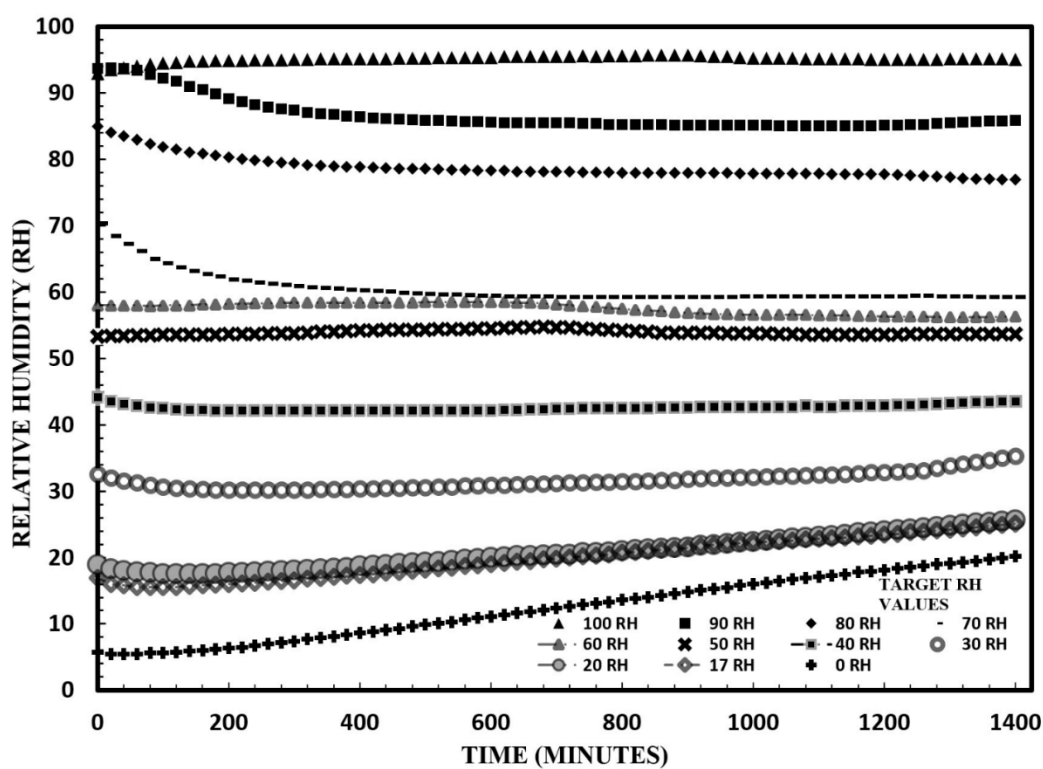
Figure 5. Measured RH values when the air pump was turned on, and air was being diffused through the glycerin-water solutions.
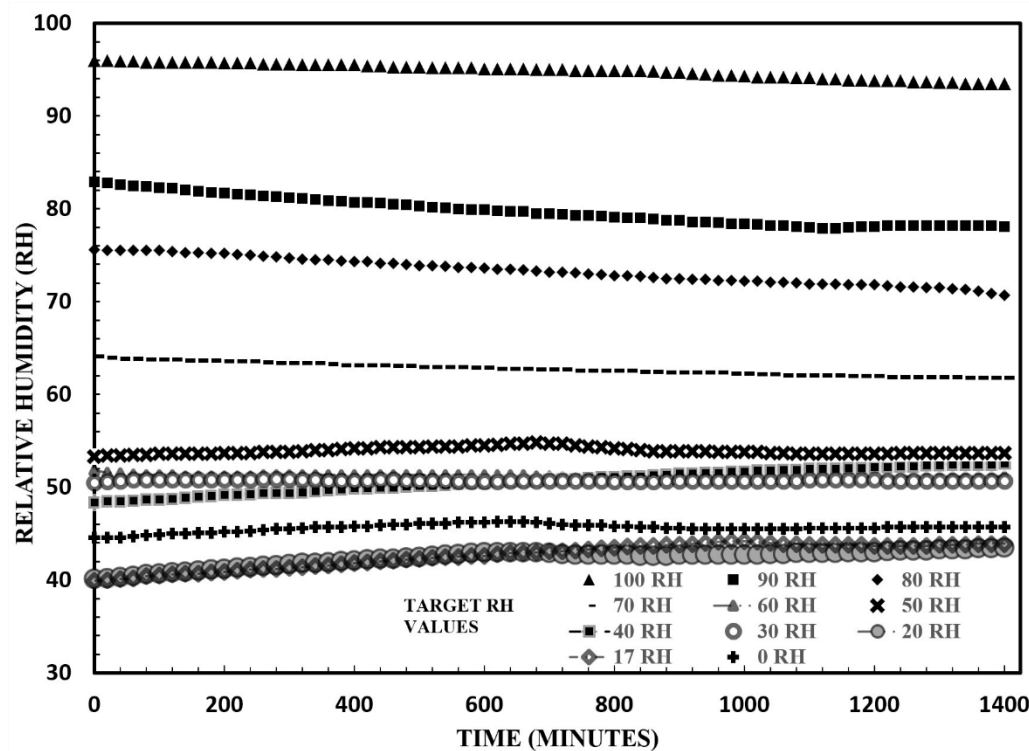

Figure 6. Measured RH values after when the air pump was turned off and the system was closed.

CONCLUSIONS

Various RH levels were created in a closed environment. The measured RH values were directly related to the ambient air temperature. Even subtle changes (0.1° C) in the room temperature caused the RH level to change. As a result, the aforementioned modifications to the system area recommended for more accurate levels of RH to be created.

ACKOWLEDGEMENTS

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