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DESIGN AND CALIBRATION OF AN AUTOMATIC RAIN SIMULATOR

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— Abstract—

In this work it was designed and built a rainfall simulator using low cost materials and easy to transport, which allowed control variables such as intensity, consistency and durability. a solenoid valve was controlled by a zero crossing detector, control board and a power stage. The results indicated that the behavior in the spatial distribution of rainfall was consistent with a value greater than 80%, intensity similar rain natural episodes with a kinetic energy greater than 27 J/mm m2, with flow control 97% precision.

Keywords

Simulated rain, droplet size, kinetic energy.

Water erosion is one of the main processes of soil degradation. Their study requires data collected over long periods (5 to 10 years). Rain simulators are research instruments designed to apply water in a manner similar to natural events. They are useful for obtaining erosion, infiltration, surface runoff and sediment transport data. This is due to the impact of rain drops as a function of kinetic energy (L. Wanga, 2014). The simulators allow to control the intensity of the applied rain, are efficient in terms of time and labor required and can be easily adapted for laboratory studies (A. Moussouni, 2014). The main characteristics of natural rainfall that must be obtained by rainfall simulators are (Sílvia CP Carvalho, 2014):

- Random distribution of raindrop size.
- Speed of impact similar to the terminal velocity of natural raindrops.
- Intensity of rain corresponding to natural conditions.
- Kinetic energy similar to that of natural rain.
- Uniform rain and random distribution of drops.

There are two types of rain simulators based on the mechanism of droplets, selected according to their availability, cost of construction and the experimental objective.

The drip method, where the initial velocity of the droplets is zero (Ibañez Asensio, Moreno Ramón, & Gisbert Blanquer, 2012), has a relatively low cost but the desired final velocity is achieved at drop heights of 12 m and in larger diameter droplets (Gopinath Kathiravelu, 2016).

The spray nozzle mechanism is one in which the water exits at an initial velocity different from zero because it is subjected to a determined initial pressure (Ibañez Asensio, Moreno Ramón, & Gisbert Blanquer, 2012). This simulator can provide rainfall of different intensity so that it is possible to simulate the characteristics of natural rainfall according to the study area (Meyer L.D., 1958) (Benito Rueda & Gomez-Ulla, 1986) , (Navas & Alberto, 1990), (Cerdá & Ibañez, 1997), (I. Abudi, 2012). The problem with this simulator is that very high intensities are required to obtain droplet sizes similar to those of natural rainfall, so they require mechanisms that allow them to be diminished while preserving the dimensions of the droplets. Rotary discs with a radial groove , a nozzle in a oscillating system , and oscillating motion sprinklers have been used in Mexico (Ognjen Gabric, 2014), (GB Paige, 2003)(Marelli, Mir, Arce, & Lattanzi, 1984) (Marelli, Arce, JM, & Masiero, & Lattanzi, 1984).

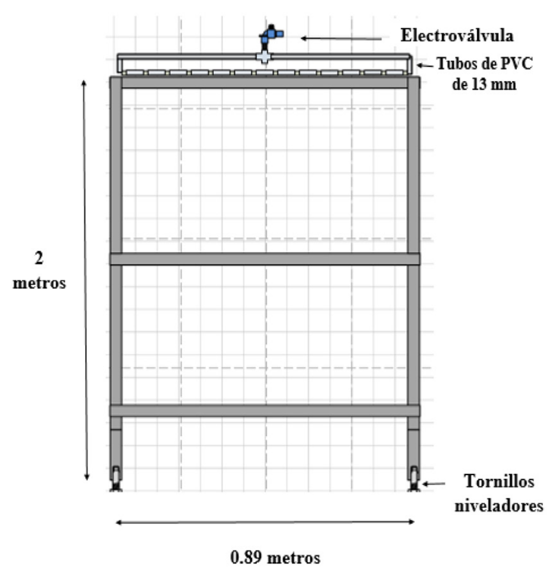
Another important feature is the size of the raindrop, as this will influence the intensity of the raindrop and the final kinetic energy. There are different techniques for its measurement using filter paper, relating the size of the stain on the paper to the size of the drop of water that caused it (Jau-Yau, Chih-Chiang, Tai-Fang, & Ming-Ming, 2008) , by means of photographs (Salvador, R; Bautista-Capetillo, C; Burguete, J; Zapata, N; Serreta, A; Playán, E, 2009), (Abudi, Carmi, & Berliner, 2012); the flour ball method (Parsakhoo, Lotfalian, Kavian, Hoseini, & Demir, 2012), and using spectropluviometers (Grismer, 2012), among others.

In this paper the characteristics and the operation of a rain simulator based on small holes made in PVC pipes are described.

Description of the simulator

A model of rain simulator, similar to the one developed by (Carreras Nampulá, García Lara, Espinoza Medinilla, González Herrera, & Medina Sansón, 2015) was designed and built with modifications in the structure and operation, taking into consideration the intensity and duration variables of precipitation (Figure 1).

Figure 1. *Structure of the rainfall simulator.*



For the management of the simulator, a zero-crossing detector and a power stage were built with an inexpensive Arduino UNO card with an easy integration with different systems and software, which allowed the generation from drops to a known flow rate using 12.3 mm PVC pipe in 0.8

m sections with holes approximately 0.8 mm in diameter spaced 2 cm apart, making a total of 481 holes (Figure 2 and 3).

Figure 2. Structure of the continuous sprinkler system.

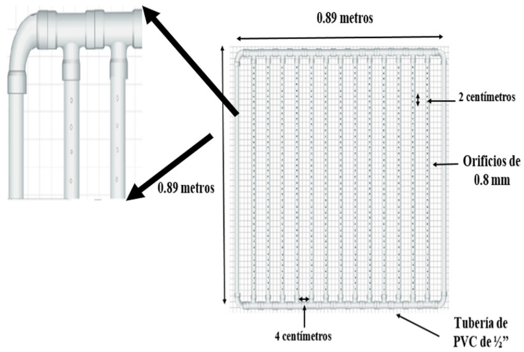
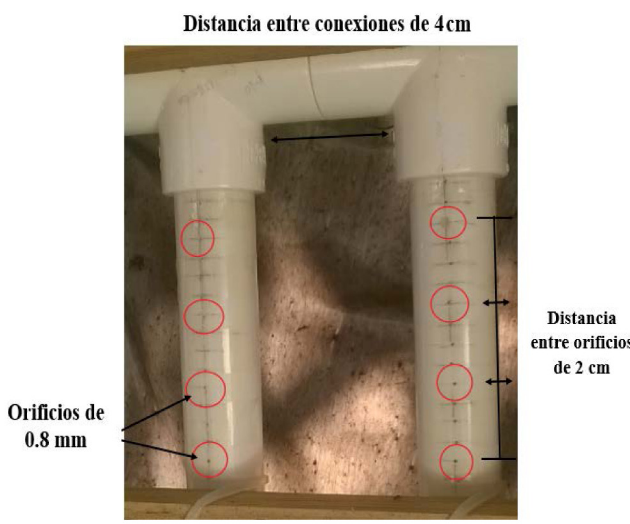


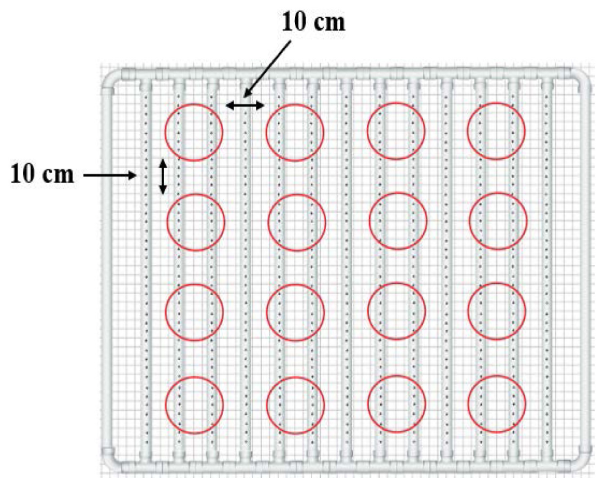
Figure 3. Dimension of the holes in the automatic system.



The flow and droplet formation was controlled using an electrovalve, which allowed it to be regulated with a maximum of 1.5 l / s, for working pressures from 20 Pa, at different intervals of time. The water supply was made using a 750 liter container and a piping system, which allowed the transport of water to the simulator. A wind shield was placed to avoid interference during the experiment.

Five trials were performed with three replicates, at 2 meters height for five different flow rates. The spatial distribution of the rain was evaluated by 16 1000 ml collectors, distributed in four rows at intervals of 10 cm between collectors and the same for each row (work area of the simulator), to determine the volume of water accumulated for 10 seconds (Figure 4). It should be noted that the number of repetitions was considered sufficient because the volume measured had a small standard deviation.

Figure 4. Spatial distribution of collecting vessels



Raindrop diameter

Due to the natural variation of raindrops, the diameter and volume were evaluated for reduced flow using a Sony brand, Cyber-shot DSC-W510 model camera with a resolution of 12.1 megapixels, 4x optical zoom and wide angle of 26 mm , which obtained images that were processed using the revolution solids technique for presentation and analysis. This method was performed by manipulating limits of sums of volumes of small sections or infinitesimal circular cuts of the revolving solid. A cylindrical layer method was used, considering the ends as spherical segments while the intermediate sections were evaluated as truncated spherical segments and the final volume was determined by:

$$V=\frac{\pi}{3}h\left(\frac{3}{4}s^2+h^2\right)+\frac{\pi}{6}\sum_{i=1}^{n-1}h\left(3a^2+3b^2+h^2\right)$$

Where h is the offset between segments, s is the diameter of each spherical segment, and while a and b are the diameters for each displacement of the spherical truncated segment.

Rainfall velocity was determined using the equation proposed by Gunn & Kinzer (1949), according to which the drops produced by the rain simulator have a terminal velocity:

$$v = 2.9379 \ln\left(D_g\right) + 4.393$$

With v, the speed (m / s) and Dg diameter in mm of the drop, the constant value of the second term should be considered as the initial velocity of the drop.

Distribución espacial de la lluvia

The kinetic energy of raindrops directly influences the separation of pollutants, particularly at the beginning of a rainfall episode (Vaze, 2003). The homogeneity of the raindrops is directly proportional to the spatial variability of rainfall intensity, and has a direct influence on the impact energy per unit area. Therefore a simulator must accurately reproduce the kinetic energy over an area of interest at a given intensity, as well as with a uniform spatial distribution. A number obtained in previous studies considered a Christiansen uniformity coefficient (CUC) of 80% or greater enough to consider rainfall patterns as realistic (Moazed, 2010). The CUC was determined by the expression:

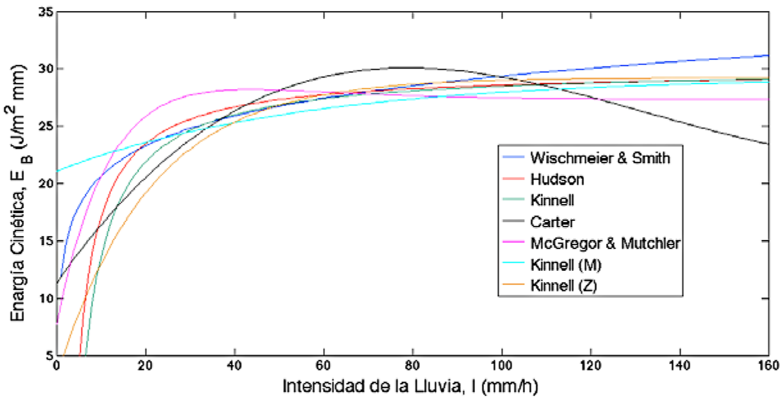
$$CUC\ (\%) = 100\left(1 - \frac{\sum x}{m\, n}\right)$$

Where m is the average value; n is the number of observations and x is the standard deviation of individual observations from the mean.

Kinetic energy

The kinetic energy of rainfall is a parameter that has been used to determine the erosion index defined in the Universal Soil Loss Equation (USLE), based on the drop size distribution. In figure 5, the different curves obtained from different mathematical expressions are presented according to the author or the area of study. (Wischmeier, 1958), (Laws, 1943), (Hudson, 1961), (Kinell, 1973) (Carter, Greer, & Braud, 1974).

Figure 5. Comparison of the relationship between kinetic energy and intensity established in different countries with different rain conditions.



In his investigations in 1973, Kinell determined that soil loss can be obtained from the total energy of the rain at intensities higher than the average acceptance rate of the soils. Because of this, it is important to obtain estimates of the relationship between the intensity and the kinetic energy of the rain by geographical areas (Rosewell, 1986). However, it is possible that the observed differences are due to the techniques used to measure raindrops. Therefore, the equation for the kinetic energy obtained by Kinell is expressed as:

$$Ec_K = e_{máx}\left[1 - a\,e^{-bI}\right]$$

Where $e_{máx}$, is the maximum kinetic energy for a given geographical area; a and b represent constants defined according to the study area.

Results

The size of the droplets generated at low pressure with a zero initial velocity, obtained a height of 5.54 mm and a diameter of 4.55 mm, and an average volume of 75.2 µ l was determined, which has a mass of 75.2 mg. With the above diameter and considering the initial velocity of the drop, it was determined that the average velocity of this drop was 4.447 m / s.

For the spatial distribution of the rain, 16 empty containers were used and were distributed on a symmetrical mesh located at ground level. The mesh sizes were 80 cm x 80 cm (6400 cm^2).

Figure 6. Intensity of the rain obtained at different electro valve control intervals .

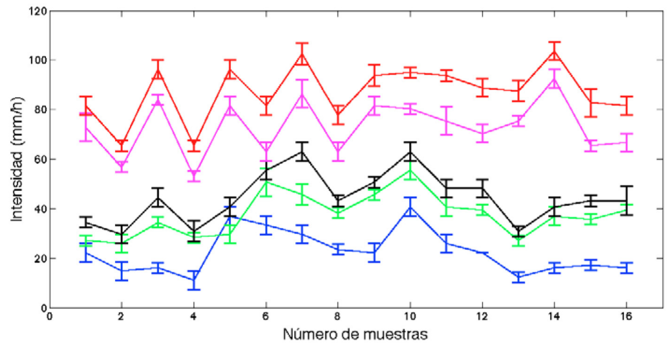
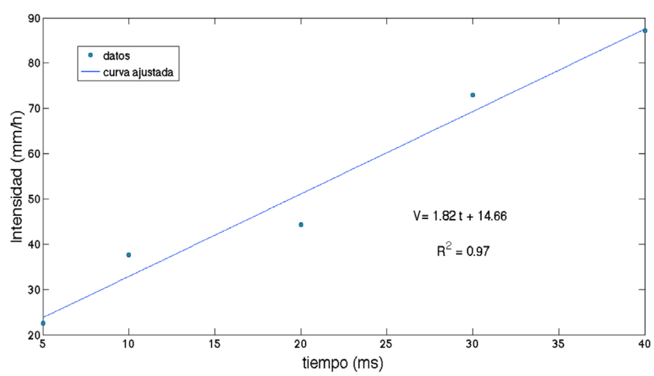


Figure 6 shows the intensity measurements performed in 10 seconds with 5 different control times on the solenoid valve (5, 10, 20, 30 and 40 ms). The CUC (%) was evaluated for each event, obtaining the following values : 69.52, 81.72, 82.46, 87.53 and 89.38, which represents a good degree of uniformity. This was achieved by modifying the structure, distributing the water pressure evenly and avoiding clearances in the pipe. However, a lower CUC was determined for the lower intensity, which was due to the minimum pressure used; on the other hand, by increasing it, good CUCs were determined for the other tests, which marks a clear relation between the pressure exerted and the CUC uniformity of the simulated rain. It is important to note that the variations present in the output intensity are also associated with imperfections in the holes that were made, residues by the perforation and the angle of the perforation in the pipe.

Figure 7. Averages of rain intensity obtained at different control intervals on the electrovalve with linear adjustment.

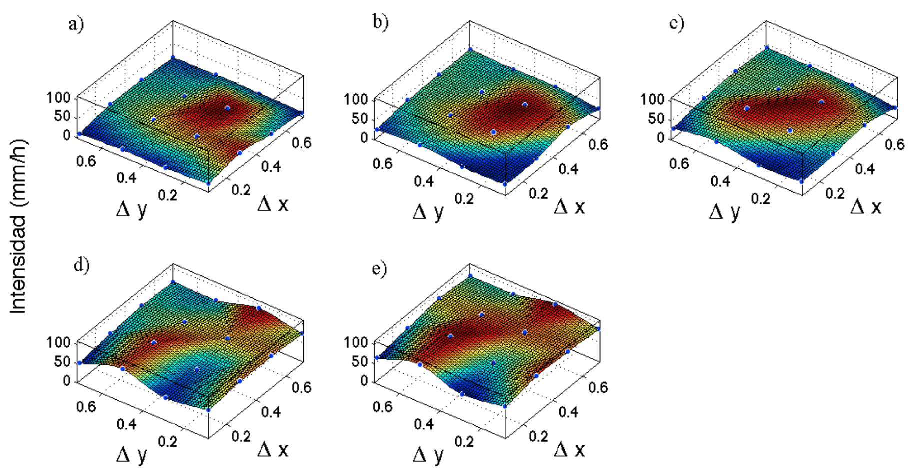


The kinetic energy (J / mm m 2) for each intensity of simulated rainfall as being 23.83, 25.13, 25.61, 27.09 and 27.59, using the Kinell model using the same coefficients calculated for Florida, due to the geographical proximity to Mexico. These values correspond to moderate to intense rainfall which is acceptable due to the search for factors that promote soil erosion.

For the development of the control of the solenoid valve, the average of the intensity was performed for each of the control times, obtaining the graph of Figure 7. This shows the linear equation that was obtained with a least square adjustment of 97% , which expresses the precision in controlling the intensity of the rain simulator in addition to the uniformity in the spatial distribution shown above.

In Figure 8, the homogeneity in the spatial distribution obtained for five different rain intensities is observed. The coefficient of uniformity obtained was 82.12% on average for the different opening times of the electrovalve, which is considered acceptable (Martínez-Mena, Abadía, & Castillo Sánchez, 2001). In spite of the mechanical adjustments made in the system, there is a tendency to focus the intensity in the central part of the impact area, so it is necessary to analyze changes in the design to minimize this effect.

Figure 8. Spatial distribution of rain intensity obtained at five different control intervals of the electrovalve a) 5 ms, b) 10 ms, c) 20 ms, d) 30 ms, and 40 ms.



Conclusions

The simulator which was built was low cost and modular, and presented at different opening times of the solenoid valve a coefficient of uniformity greater than 90%. For a pressure of 20 Pa, with a flow rate of 1.5 l / s and a height of 2 meters, droplet diameter of 4.5467 mm and a kinetic energy of 23.83 for a shower of low intensity was obtained , up to 27.59 J / mm m 2 which corresponds to a very intense rain. A a coefficient of uniformity of 82.12% was obtained, which is considered acceptable. From the simulation of rain was obtained a least squares adjustment of 97% which indicates a high repetitiveness of the system, achieving a simulated rainfall set compared to those presented in the natural events. A system was developed and evaluated that intends to study future soil erosion problems due to precipitation, simulating real conditions of a natural rainfall.

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