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Influence of Concentration and Type of Clay Particles on Dripper Clogging

Oliveira FC[1], Lavanholi R[1], Camargo AP[1]*, Frizzone JA[1], Ait-Mouheb N[2], Tomas S[2] and Molle B[2]

[1]Department of Biosystems Engineering, Luiz de Queiroz College of Agriculture, University of São Paulo, Piracicaba, São Paulo, Brazil
[2]National Research Institute of Science and Technology for Environment and Agriculture, UMR G-EAU Montpellier, France

Abstract

The leading causes of emitters' clogging are known, although the processes involved are seldom studied. The present research is based on the hypothesis that the susceptibility of drippers to clogging is influenced by the emitter discharge, the type of clay, and the concentration of clay in the irrigation water. The objective of this study was to analyse the susceptibility of drippers to clogging caused by water containing suspended clay particles. The susceptibility of the drippers to the clogging was analysed with respect to the following factors: the concentration of suspended clay in water, the discharge of emitters of same labyrinth geometry, and the type of clay particles in suspension. We used four concentrations of kaolinite and montmorillonite (500, 750, 1,000, and 2,000 mg L^{-1}) and two drip line models with similar labyrinth geometries, one model having a lower flow rate (0.6 L h^{-1}) than the other (1.7 L h^{-1}). The concentration of suspended clay particles affected the flow rate of the drippers, particularly at concentrations above 1000 mg L^{-1}. The drip line model with the lower flow rate was more susceptible to variations in the flow rate than the higher-flow rate model. The type of clay had no significant effect on the dripper clogging.

Keywords: Plugging; Emitter; Clay particles; Flow rate; Micro irrigation

Introduction

Clogging of emitters has been identified as the main limitation of microirrigation systems. In addition to reducing the durability of equipment [1], it can compromise the water application uniformity [2,3]. The uniformity of distribution is an important parameter for the performance of irrigation systems, as it expresses the variations in volume of water applied at different points on a given surface. In particular, in areas where fertigation occurs, a high uniformity of distribution is essential to ensure that plants receive equivalent amounts of nutrients [4].

Clogging can be caused by different factors (physical, chemical, or biological) [5]. Clogging caused by physical processes has been identified as the most common type and is due to particles in suspension. Generally, these particles are part of the soil and can be classified according to their mean diameter, as follows: sand (2 to 0.05 mm), silt (0.05 to 0.002 mm), and clay (less than 0.002 mm) [5,6].

Clay particles are usually too small to clog drippers. However, small-diameter particles can pass through the filtering system and reach the drippers [7]. Inside the drippers, depending on the characteristics of the flow in the labyrinth, particles can be deposited in the vortices and stagnation zones, increasing the potential of clogging [8,9].

Although the main causes of clogging are known, thorough studies on the processes involved are lacking. The present study is based on the hypothesis that the susceptibility of drippers to clogging is influenced by the emitter flow rate, the type of clay, and the concentration of clay in the irrigation water. To further our understanding of the clay clogging process, the objective of this study was to analyse the susceptibility of drippers to clogging caused by water containing suspended clay particles. We analysed the performance of drippers exposed to water containing clay particles in suspension. To study the susceptibility of the drippers to clogging, the following factors were analysed: the concentrations of clay suspended in water, the flow rate of drippers having the same labyrinth geometry, and the types of clay particles in suspension (kaolinite and montmorillonite).

Materials and Methods

The experiment was performed on a workbench designed for clogging tests, at the ESALQ/USP Irrigation Material Testing Laboratory in Piracicaba, SP.

The test bench was equipped with a 250 L water reservoir, a pump, a mixer, a manifold with symmetrical bifurcations, a set of collectors and an automated system for the continuous flow rate monitoring of 32 drippers. The water flow was equally distributed among eight lateral lines of equal length (2.8 m), set up in parallel.

The test pressure (100 kPa) was monitored using a digital pressure gauge installed at the top of one of the lateral lines. The collectors were equipped with pressure transducers (Motorola/Freescale-MPX5010DP) connected to a data-acquisition system, which were used for monitoring the variations of the water level and the subsequent calculation of the flow rates of the drippers. Pinch solenoid valves were installed in the bottom part of the collectors, for drainage. The water drained by the collectors was channelled to the reservoir through gutters, perpetuating water recirculation through the system.

Two types of clay compounds were used in this study: (1) kaolinite (Kt), clay type 1:1, density of 2419.9 kg m^{-3}, 2.651-μm average diameter of particles, commercial brand named kaolin extracted from a mineral source located at Pântano Grande, Rio Grande do Sul, Brazil; (2) montmorillonite (Mt), clay type 2:1, density of 2364.2 kg m^{-3}, 2.296 μm average diameter of particles, commercial brand named Brasgel provided by the company Bentonit União Nordeste S.A. (Brazil). Kt was selected because of its abundance in surface waters, and Mt was

***Corresponding author:** Camargo AP, Department of Biosystems Engineering, Luiz de Queiroz College of Agriculture, University of São Paulo, Piracicaba, São Paulo, Brazil, Tel: +55 19 3447-8574; E-mail: apcpires@usp.br

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chosen for its sensitivity to the physicochemical and hydrodynamic conditions that may lead to aggregation phenomena in irrigation systems.

The flow rate of the drippers was initially determined using distilled water, without adding particles, to avoid the risk of clogging. This flow rate is referred to as the initial flow (qi). Further testing was subsequently performed with clay particles in suspension, resulting the final flow (qf).

The effect of the concentration of clay particles on the susceptibility of the drippers to clogging was studied intermittently over 40 h, by alternating between 8-h operation periods and 16 h of rest. From one concentration to the other, the drip lines were replaced with new ones, and the bench was cleaned in order to avoid residual effects on future tests.

We attempted to maintain the pH of the water at approximately 6 to reduce the risk of ions precipitation and the biological activity. pH corrections were performed when necessary by using hydrochloric acid (HCl).

The sensitivity of drippers to clogging was assessed based on the average values of the relative flow rate (average of 15 drippers). The average value was obtained over an 8-h testing period, corresponding to 384 automated flow rate measurements. The relative flow rate (qr) was expressed as a percentage and it depends on the initial flow rate (qi) and final flow rate (qf) of the drippers (equation 1).

$$q_r = 100\frac{q_f}{q_i} \quad (1)$$

The results were presented in graphs, indicating the average relative flow rate as a function of the elapsed testing time. Values of the average relative flow rate are written above whiskers. Whiskers indicate standard deviation ranges. Additionally, the mean values are followed by a letter used to indicate if the average values are significantly different from each other. Mean values followed by the same letter does not present significant difference in statistical terms. The experimental design was completely randomized, and a Tukey's test ($p<0.05$) was performed to compare the relative flow rate averages obtained for a given tested parameter over the same period of time. The Turkey's test is a statistical test that can be used to find whether mean values are significantly different from each other or not.

Four concentrations of each clay compound (Kt and Mt) were analysed. The concentrations used were C1 (500 mg L^{-1}), C2 (750 mg L^{-1}), C3 (1000 mg L^{-1}), and C4 (2000 mg L^{-1}).

Two non-pressure compensating flat drippers were tested. Fifteen drippers of each model were evaluated simultaneously. Drip lines of the Naan Dan Jain® brand and the Tal drip model were selected because the emitters have similar geometries, with flow rates of 0.6 L h^{-1} (model A) and 1.7 L h^{-1} (model B) (Table 1).

Results and Discussion

Figure 1 shows the effect of the kaolinite (Kt) concentration on the flow rate of drip line model A with respect to the testing time. At the concentration C1, there was a progressive decrease in the relative flow rate, with a reduction of 2% after 40 h of testing. The C2 concentration results a flow rate reduction of 7% after 24 h of testing, and subsequently there was a small increase in the flow rate (1%), which was then maintained until the end of the 40-h testing period. The same trend was observed for the concentration C3, with an initial reduction of 5% after 16 h and a subsequent increase (1%), followed by the flow rate remaining relatively constant until the end of the test. The higher concentration (C4) yielded a greater fluctuation of the relative flow rate values. On the first day of testing (8 h), the reduction reached 2%; then, a progressive increase occurred, with the flow rate returning to the initial value after 24 h of testing. Finally, after 40 h of testing, there was a reduction of 9% in the relative flow rate.

Analysis of the concentrations at each testing time step reveals that no significant difference occurred on the first day (8 h). Significant differences began to appear after 16 h. At 16 h, the concentration C3 led the smallest reduction (5%). At 24 h, the concentration C2 yielded the smallest reduction (7%). After 32 and 40 h of testing, the concentrations C2 and C4 were similar and differed from the concentration C1.

The increase in Kt concentration did not significantly influence the flow rates of the model B drippers. The flow rate reductions over time were not significant, even after 40 h of testing. The largest reduction (4%) was obtained for the highest concentration of particles (C4). However, there was no significant difference between the average discharge at each concentration and at any testing time, except at 16 h, when there was a difference between the concentrations C1 and C2 (Figure 2).

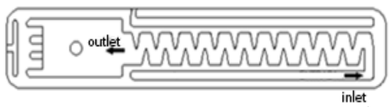
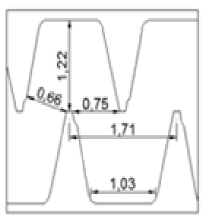
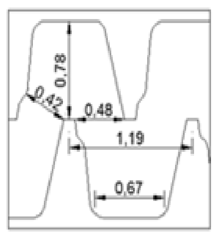
Manufacturer/Model	NaanDanJain/Taldrip	NaanDanJain/Taldrip
Nominal discharge (L h^{-1})	1.7	0.6
Average discharge under 98.1kPa (L h^{-1})	1.55	0.55
Coefficient of variation - CVq (%)	1.7	2.0
Design		
Labyrinth dimensions (top view / units=mm)		
Labyrinth depth (mm)	0.71	0.42

Table 1: Characteristics of the evaluated dripline models.

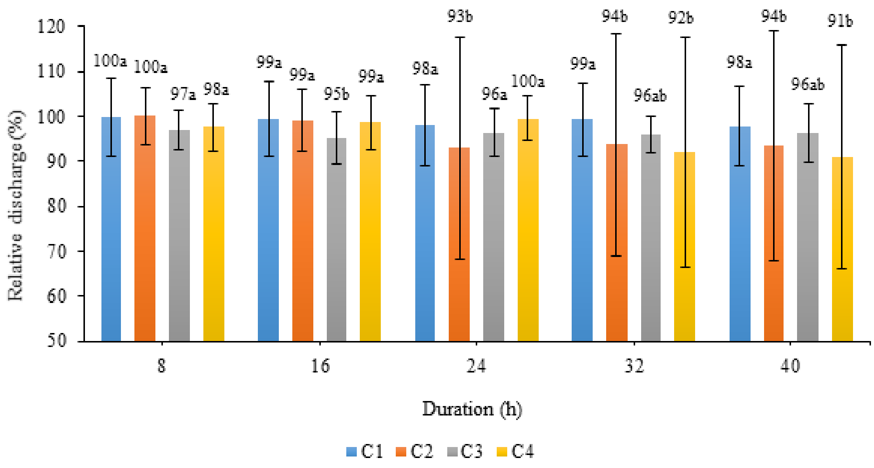


Figure 1: Effect of the concentration of Kt particles in the suspension — C1 (500 mg L^{-1}), C2 (750 mg L^{-1}), C3 (1,000 mg L^{-1}), and C4 (2,000 mg L^{-1}) — on the clogging for dripline model A (0.6 L h^{-1}).

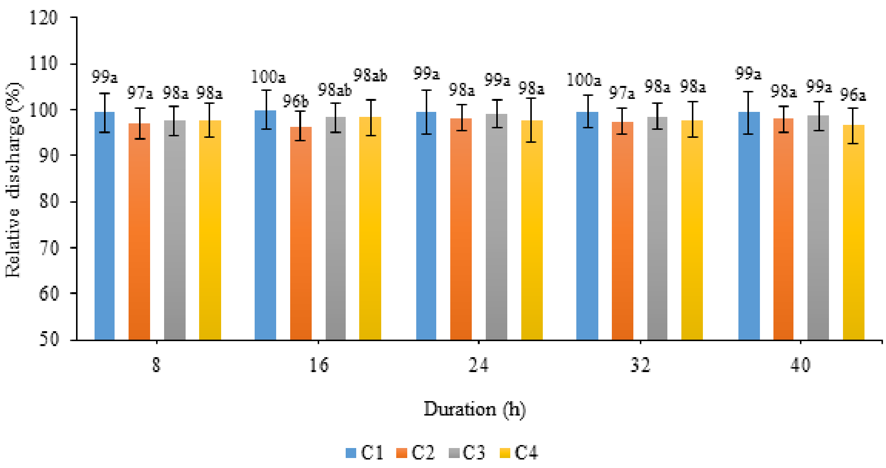


Figure 2: Effect of the concentration of Kt particles in the suspension — C1 (500 mg L^{-1}), C2 (750 mg L^{-1}), C3 (1,000 mg L^{-1}), and C4 (2,000 mg L^{-1}) — on the clogging for dripline model B (1.7 L h^{-1}).

In evaluating the effects of the concentration of Mt on the performance of dripper model A, throughout the test, the concentrations C3 and C4 resulted in the greatest reduction in the flow rate, although there was no significant flow rate difference between them (Figure 3). The concentrations C1 and C2 yielded smaller flow rate reductions, being statistically similar and differing from the concentrations C3 and C4. The largest flow rate reductions (18% and 14%) occurred after 8 h of testing, at the concentrations C3 and C4, respectively. During the test, the flow rate reduction decreased progressively, reaching 9% for both concentrations at the end of the test.

The Mt concentrations caused different flow rate behaviours for dripper model B compared with model A. In general, the flow rate reductions were smaller, with the largest reduction observed for the concentration C3 after 8 h of testing (14%) (Figure 4). After 40 h of testing, there was no flow rate reduction for the concentration C1, and there was a 3% reduction for the concentration C2. This reduction is statistically similar to that (4%) for the concentration C4.

The Mt particles induced more fluctuations on relative flow rates than Kt particles, though the effects of the particle concentration on the relative flow rate of the drippers were statistically similar for the two types of clay. In general, the flow rate reduction tends to be greater at clay concentrations higher than 1,000 mg L^{-1}. For future studies using clay particles, we suggest the use of concentrations higher than that, as lower concentrations did not result in significant effects on the performance of the drippers. In addition, higher concentrations of salt and other pH values could be tested to change the potential of particles aggregation. Finally, exposure times longer than 40 h could influence flow rate fluctuations of drippers.

The concentrations of clay particles that led the greatest flow rate reductions were higher compared with the classification for a severe clogging risk (400 mg L^{-1}) caused by suspended particles [10]. The results of the present study support the classification that considers particles with diameters less than 0.031 mm to be unlikely to cause clogging of drippers [7].

Physical clogging caused by suspended particles depends on two factors: i) the concentration and ii) the diameter of particles. A suitable

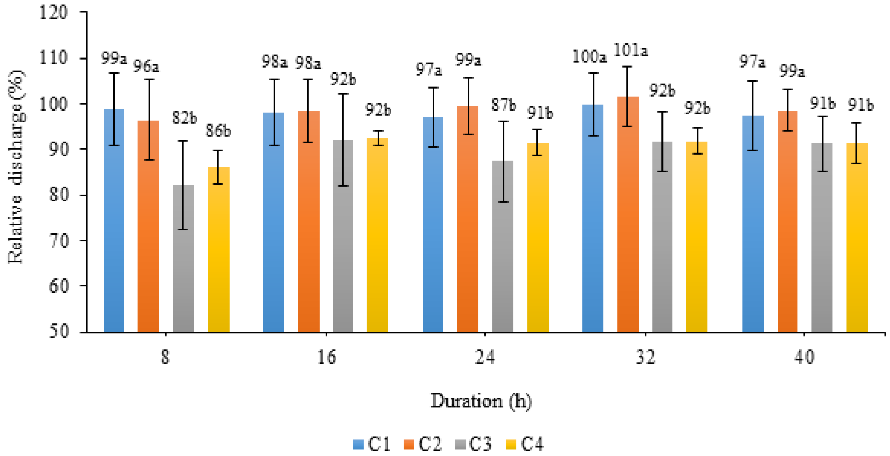


Figure 3: Effect of the concentration of Mt particles in the suspension — C1 (500 mg L⁻¹), C2 (750 mg L⁻¹), C3 (1,000 mg L⁻¹), and C4 (2,000 mg L⁻¹) — on the clogging for dripline model A (0.6 L h⁻¹).

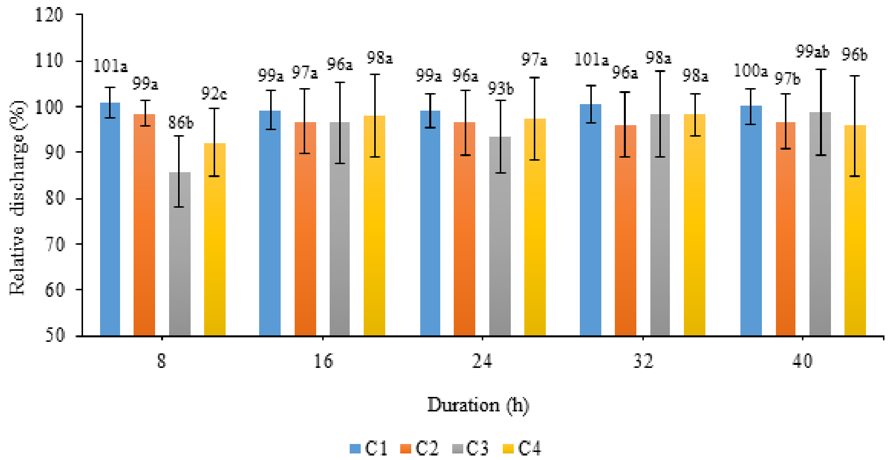


Figure 4: Effect of the concentration of Mt particles in the suspension — C1 (500 mg L⁻¹), C2 (750 mg L−1), C3 (1,000 mg L⁻¹), and C4 (2,000 mg L⁻¹) — on the clogging for dripline model B (1.7 L h⁻¹).

classification for the risk of clogging caused by suspended particles might factor in the effect of the interaction between these two variables on the dripper performance.

The fluctuation of flow rates over time was observed in previous studies for small particles, such as fine sand, silt [7], and clay [9]. The results are attributed to a self-cleaning phenomenon that occurs inside the labyrinths each time irrigation system is switched on. In researches that aim to improve the performance of drippers, self-cleaning is considered an alternative that should be explored in drippers design phase to provide emitters less susceptible to clogging [11]. Additionally, when adding clay particles, the flow rate of non-pressure compensating drippers [9] and pressure-compensating drippers [12] has been reported to increase in some test conditions.

Concerning the different dripper models under study, Model A (0.6 L h⁻¹) was more susceptible to flow variations than model B (1.7 L h⁻¹) (Figures 1-4). The greater sensitivity to clogging of drippers of lower flow rates, compared with higher-flow rate drippers, is mainly attributed to the smaller dimensions of the labyrinths in the low-flow rate drippers (Table 1), which offer a smaller cross-section for passage and thus results in a greater sensitivity to clogging [13-15].

The deposition of particles that promote drip clogging occurs mainly at the first baffles of the labyrinth [7] near vortices and stagnation regions, where the flow velocity and turbulent kinetic energy are lower than other regions of the labyrinth [9,16].Concerning the type of clay particles, although the Mt caused a greater reduction of the flow rate, at the concentrations C3 and C4, at the end of the first day of testing, both Kt and Mt exhibited a reduction of 9% in the flow rate, for the model a dripper.

For these types of clay to manifest their potential for clogging, it is necessary to change in the physicochemical characteristics of the solution, e.g., increasing the concentration of salts and/or changing the pH value of the solution. In this manner, conditions that favour the aggregation process can be obtained by increasing the size of the aggregates. Larger particles can change the water flow inside the labyrinths, interfering with the dripper performance [9,16].

Regarding to methods to assess the sensitivity of drippers to clogging under controlled conditions, the following remarks should be considered by further related activities. The technical committee ISO/TC23/SC18 is discussing a standard protocol to evaluate the sensitivity of drippers to clogging related to water characteristics in controlled (laboratory) and natural (field) conditions [17]. Considering the effect of electric charges of clay particles and the possibility for these particles to build up aggregates [7], it would be advised using a mixing of different sizes of particles (i.e., clay, silt and sand), as proposed in the framework of the committee ISO/TC23/SC18.

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