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Experimental Analysis of Colloid Capture by a Cylindrical Collector in Laminar Overland Flow

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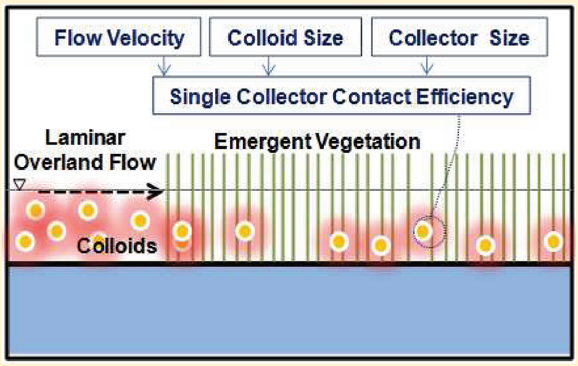
ABSTRACT: Although colloid-facilitated contaminant transport in water flow is a well-known contamination process, little research has been conducted to investigate the transport of colloidal particles through emergent vegetation in overland flow. In this work, a series of laboratory experiments were conducted to measure the single-collector contact efficiency (η_0) of colloid capture by a simulated plant stem in laminar lateral flow. Fluorescent microspheres of various sizes were used as experimental colloids. The colloid suspensions were applied to a glass cylinder installed in a small size flow chamber at different flow rates. Two cylinder sizes were tested in the experiment and silicone grease was applied to the cylinder surface to make it favorable for colloid deposition. Our results showed that increases in flow rate and collector size reduced the value of η_0 and a minimum value of η_0 might exist for a colloid size. The experimental data were compared to theoretical predictions of different single-collector contact efficiency models. The results indicated that existing single-collector contact efficiency models underestimated the η_0 of colloid capture by the cylinders in laminar overland flow. A regression equation of η_0 as a function of collector Reynolds number (Re_c) and Peclet number (N_{Pe}) was developed and fit the experimental data very well ($R^2 > 0.98$). This regression equation can be used to help construct and refine mathematical models of colloid transport and filtration in laminar overland flow on vegetated surfaces.



INTRODUCTION

Transport of colloidal particles in water flow is an important contamination process that can pollute both surface water and groundwater. Suspended colloids are capable of carrying a variety of contaminants and enhance their mobility in aquatic systems.[1] Movement of colloidal particles in soils may also affect their productivity, nutrient cycling, and species composition.[2]

A substantial research effort has been made to understand colloid and colloid-facilitated transport in porous media including the vadose zone and groundwater. Bench-scale packed column experiments have been conducted to examine the transport behaviors of different types of colloids, including viruses, bacteria, clay particles, synthetic microspheres, and engineered nanoparticles.[3−6] Relationships between system physicochemical properties (e.g., flow velocity, solution chemistry, and surface properties) and colloid mobility in porous media were evaluated.[7−10] In addition, the influences of biological factors (e.g., cell size and shape, cell motility, and micromolecular length and composition) on biocolloid fate and transport in porous media have been assessed.[11,12] Findings from these investigations have enhanced current ability to predict and monitor the fate and transport of colloidal particles in subsurface flow.

Considerably less attention has been dedicated to the fate and transport of colloidal particles in surface flow, particularly with respect to colloid transport through vegetation in overland flow.[13−15] Several studies have shown that vegetation structures (submerged or emergent) can remove suspended particles including colloidal particles from surface flow.[15−17] Leonard et al [18] observed that the capture of suspended particles on the stems and leaves of *Juncus roemerianus* marsh contributed up to 10% of the total sediment deposition to a tidal marsh. Similarly, Pluntke and Kozerski [19] suggested that sedimentation onto plant structures should be considered when quantifying particle retention in submerged macrophyte stands. Particle retention in a sea grass meadow (*Posidonia oceanica*) was found to be up to 15 times greater than the equivalent nonvegetated bed.[20] In a wetland field site in the Florida Everglades, Huang et al. [17] found that aquatic vegetation could remove colloidal particles from surface flow. This evidence strongly suggests that filtration by plant structures, such as stems, has a significant effect on the fate and transport of colloidal particles in surface flow. Unfortunately, current understanding of the capture of colloidal particles by plant structures in surface water is still very limited.

In laminar overland flow, the depth of water is usually below the top of the sheaths of grassy vegetation and only plan stems are underwater to affect flow and transport processes.[21,22] Under many practical conditions, plant stems can be modeled as rigid cylinders (e.g., nails and rods) in flow and transport studies.[23−25]

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Therefore, establishing a single-collector efficiency theory of colloids captured by small size cylinders can help advance understanding of colloid fate and transport in surface flow. The single-collector concept has not only been widely used in colloid filtration in porous media,[26,27] but has also been successfully applied to sediment removal by aquatic plants.[24] However, only a few studies have directly measured particle capture by a single collector, particularly with respect to a spherical or cylindrical collector.[24,28] Palmer et al. [24] measured the single-collector efficiency of sediment capture on a cylindrical collector under various conditions. Their measurements validated the mathematical models of single-collector contact efficiency of suspended sediments in wetland systems (i.e., submerged vegetation). Nevertheless, it is unclear whether existing models can be used to describe the capture of colloidal particles (much smaller than sediments) on a cylindrical collector in nonsubmerged, surface vegetation systems with shallow overland flow.

In this work, laboratory experiments were conducted to measure the single-collector contact efficiency of colloid capture by a cylindrical collector in laminar overland flow. A glass cylinder installed in a small size flow chamber was used as the collector. Silicone grease was applied to the collector surface to facilitate colloid deposition. Fluorescent microsphere suspension was used in the experiment. The amount of colloids deposition onto the cylinder surface was measured to determine the single-collector contact efficiency under various experimental conditions. Our objectives are as follows: (1) determine how flow velocity, colloid size, and collector size affect the single-collector efficiency of colloid capture by a cylindrical collector in laminar overland flow, (2) test whether existing single-collector contact efficiency models can be used to predict colloid capture by a cylinder in laminar overland flow, and (3) develop a regression equation to describe the single-collector efficiency of colloid transport through emergent vegetation in laminar overland flow.

THEORY

The contact efficiency of a single collector (η_0) is a ratio of the rate at which colloids strike the collector divided by the rate at which colloids flow toward the collector.[26] The magnitude of η_0 is assumed to be controlled by three transport mechanisms: interception, sedimentation, and diffusion. Interception takes place when a suspended colloid moving along flow streamlines come into contact with the collector by virtue of its size. Sedimentation occurs when a suspended colloid has a density greater than the fluid density, and the particle can then collide with a collector. Diffusion reflects the Brownian motion of the suspended colloid in fluid that leads to diffusive transport of the particle to the collector surface. The interception and sedimentation processes contribute significantly to the single-collector contact efficiency for colloids with diameters greater than 1 μm; while the diffusion mechanism becomes significant when colloids are smaller than 1 μm.[26,27,29] Because the sedimentation process is gravity driven, it affects the single-collector contact efficiency only when the collectors are assembled along the gravity line. In case of laminar overland flow on a flat surface or a moderate slope, we can assume the contribution from the sedimentation processes to η_0 is insignificant. If only interception and diffusion transport mechanisms are considered, then the single-collector contact efficiency of colloids in laminar overland flow captured by a cylinder can be expressed as follows:

$$\eta_0 = \eta_I + \eta_D \tag{1}$$

where η_I and η_D are the contributions from interception and diffusion, respectively. Usually the contact efficiency of each mechanism is first determined separately and then the overall single-collector contact efficiency can be obtained by summing the individual contributions.[26,27,29]

Several models have been developed to calculate the single-collector contact efficiency of colloids, but almost all of them are for spherical collectors. For example, the Yao,[26] RT,[27] and TE [29] models have been widely used to determine the single-collector contact efficiency of colloid filtration in porous media. It is unclear whether these models can be applied to describe the single-collector contact efficiency of colloids to a cylinder collector.

Recently, Palmer et al. [24] established a theory to calculate the single-collector contact efficiency of suspended sediments for cylindrical collectors in aquatic systems. On the basis of their approach, each component of the single-collector contact efficiency of the cylindrical collector can then be determined analytically as functions of the particle/collector size ratio ($R = d_p/d_c$, where d_p is particle diameter and d_c is cylinder diameter in this case), and the collector Reynolds number (i.e., collector diameter-based Reynolds number), $Re_c = ud_c/\nu$, where u is flow velocity, and ν is the kinematic viscosity.[24] For instance, under creeping flow conditions (i.e., $Re_c < 1$), particle contact efficiency due to direct interception (η_I) to a cylinder can be expressed as follows:[30]

$$\eta_I = \frac{1}{(2 - \ln Re_c)}\left[(1 + R)\ln(1 + R) - \frac{R(2 + R)}{2(1 + R)}\right] \tag{2}$$

The contact efficiency due to colloid diffusion (η_D) for creeping flow can be written as follows:[31]

$$\eta_D = \frac{1.17\pi D^{2/3}}{ud_c}\left[\frac{Re_c \nu}{2(2 - \ln Re_c)}\right] \tag{3}$$

where D is the particle diffusion coefficient, which can be obtained from the Einstein's diffusion equation.[32] Equations 2 and 3 are based on the aerosol filtration theory of mass transfer to a cylinder, which could be very similar to transport and deposition of colloids in overland flow through emergent dense vegetation. Therefore, we conducted a range of experiments to test whether the single-collector contact efficiency equations can be used to describe the capture of colloids by the cylindrical collector in laminar overland flow.

MATERIALS AND METHODS

Colloids and Collectors. Fluorescent, carboxylated, polystyrene latex microspheres (Magsphere, Inc.) of four different sizes (0.1, 1.05, 2.0, and 10.5 μm) were used in the experiment as model colloids. The density of the colloids, as reported by the manufacturer, was 1.05 g/cm^3. Colloid suspensions for testing were made by diluting the stock solution (1.05 g/mL, corresponding to 1.0×10^{15}, 8.6×10^{11}, 1.2×10^{11}, and 8.6×10^{8} no./mL for 0.1, 1.05, 2.0, and 10.5 μm colloids) to the target concentrations (10 mg/L, corresponding to 1.0×10^{10}, 8.6×10^{6}, 1.2×10^{6}, and 8.6×10^{3} no./mL for 0.1, 1.05, 2.0, and 10.5 μm colloids) with deionized (DI) water. The pH of the colloid suspensions were around 5.3.

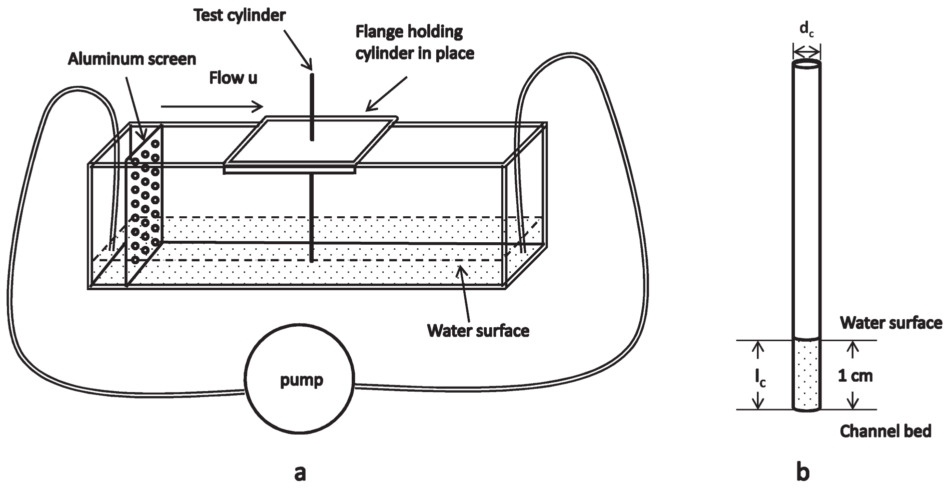


Figure 1. Schematic of experimental setup for measuring single-collector contact efficiency.

Two glass cylinders of diameters 1.0 and 2.0 cm were used in the experiment as the collectors to simulate plant stems. Clear silicone grease (Baysilone, GE Bayer) was applied to the collector to mark off a 1 cm test section at the bottom end (Figure 1) to ensure deposition of colloids on the collector area and make the attachment efficiency (α) equal to one.[24] The final grease thickness (≪0.5 mm) was regarded as not thick enough to significantly change the diameter of the cylinder. This process was repeatable such that the grease layer thickness was constant every test. The glass-cylinders covered with silicone grease provide a good representation of rigid plant stems with sticky surfaces.[24] In natural vegetation systems, underwater plant surfaces are often covered with sticky layers, such as epiphytes, organic biofilm, guttation liquid, and resinous trichomes.[24,33]

Experimental Apparatus. The experimental apparatus used in this study was similar to that of Palmer et al. [24] but at a much smaller scale (Figure 1). The main component was an open flow channel flow chamber made of Plexiglas of 20 cm long, 10 cm wide, and 10 cm high. A recirculating peristaltic pump (Masterflex L/S, Cole Parmer) was used to provide the desired system flow velocities. An aluminum screen (holes diameter 3.0 mm, 55% open area) was installed in the flow chamber to stabilize flow across the section. A flat velocity profile could be obtained near the center part of the flow channel as long as low velocities (<0.3 cm/s) were used. Therefore, the longitudinal location 5 cm downstream of the inlet was chosen for the cylinder test position. The water depth in the flow chamber was controlled to be slightly above 1 cm to ensure that the collector area was under water surface.

Experimental Methods. Before each test, the flow channel, the pipe, and the collector were cleaned thoroughly with DI water. The colloid suspension was then poured into the flume, and then stirred until the colloids spread out over the whole channel. A peristaltic pump was then used to circulate the flow in the chamber system for about 2 min. After the flow system properties (i.e., flow rate, water table, colloid distribution) stabilized, the cylinder collector was then carefully positioned into the chamber for durations of 5, 10, 30, 60, or 120 min. Nine different flow velocities (0.02−0.2 cm/s), two collector sizes (1 and 2 cm), and four colloid sizes (0.1−10.5 μm) were tested in the experiment (Table 1). The Re_c values in the work were between 0.42 to 42, corresponding to both low and high laminar flow conditions.[34] At the end of each run, the flow was stopped and the collector was gently pulled out to measure the amount of colloids attached. Pre-experimental tests showed that the colloids attached to the silicon grease on the collector surface can be fully recovered with a 4% surfactant (sodium dodecylbenzene sulfonate, 10 mL) solution. A fluorescent spectrophotometer (PerkinElmer LS 45) was used to determine the amount of colloids recovered. Each experiment was repeated at least three times. The colloid capture rate (r_c) by the collector was determined by measuring the increases in number of colloids on the collector over different time intervals.

$$r_c = \frac{\Delta N}{\Delta t} \quad (4)$$

where ΔN is the number of colloids increased on the collector surface over a time interval (Δt). Thus, the single-collector contact efficiency (η_0) of colloids captured by a cylindrical collector in laminar flow can be written as follows:

$$\eta_0 = \frac{r_c}{N_0 u d_c l_c} \quad (5)$$

where N_0 is the number of colloids in the suspension, u is the flow approach velocity, d_c is the diameter of collector, and l_c is the height of coated area of collector.

■ RESULTS AND DISCUSSION

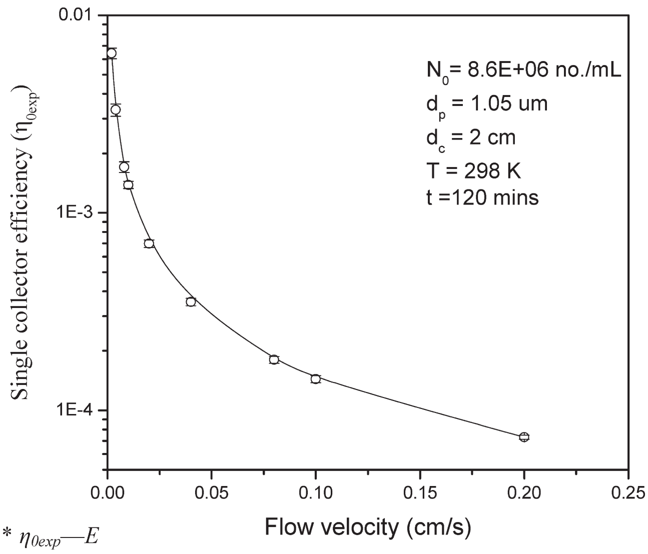
Effects of Flow Velocity and Colloid and Collector Sizes. For all the experimental conditions tested, the number of colloids increased on the collector surface (ΔN) and the experimental time intervals (Δt) showed good linear relationships with almost all R^2 larger than 0.9 except one (Table 1). Therefore, the slopes of the linear regressions were used as the colloid capture rates (r_c) to determine the experimental single-collector contact efficiencies (η_0). Standard deviations of η_0 were computed for three replicate trials to estimate the uncertainties (Table 1). These results demonstrated the dependence of η_0 on flow velocity (u), colloid particle diameter (d_p), and collector diameter (d_c).

Increases in u reduced η_0 when d_p and d_c were 1.05 μm and 2 cm, respectively (Figure 2). For example, η_0 decreased by 2 orders of magnitude when the u increased from 0.002 to 0.2 cm/s, indicating a negative correlation between the single-collector

Table 1. Summary of Experimental Conditions and Results

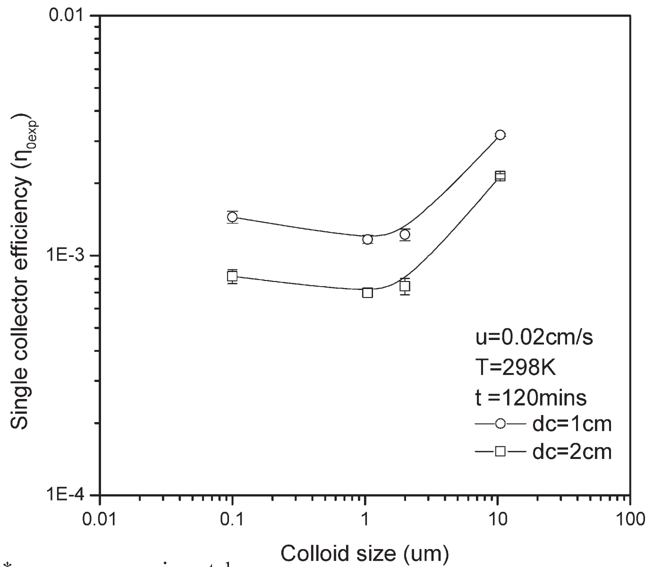
test no.[a]	particle diameter d_p (μm)	flow velocity u (cm/s)	collector diameter d_p (cm)	increased colloids no. as a function of time intervals (r_c=$\Delta N/\Delta t$)	R^2	single-collector contact efficiency (η_0) mean (%)
I.1	1.05	0.002	2	13310 ± 821	0.991	$6.4 \times 10^{-3} \pm 4.0 \times 10^{-4}$
I.2	1.05	0.004	2	13764 ± 969	0.994	$3.3 \times 10^{-3} \pm 2.3 \times 10^{-4}$
I.3	1.05	0.008	2	14145 ± 899	0.990	$1.7 \times 10^{-3} \pm 1.0 \times 10^{-4}$
I.4	1.05	0.01	2	14346 ± 600	0.986	$1.4 \times 10^{-3} \pm 5.8 \times 10^{-5}$
I.5	1.05	0.02	2	14477 ± 629	0.991	$6.9 \times 10^{-4} \pm 3.0 \times 10^{-5}$
I.6	1.05	0.04	2	14656 ± 629	0.989	$3.5 \times 10^{-4} \pm 3.0 \times 10^{-5}$
I.7	1.05	0.08	2	14934 ± 629	0.981	$1.8 \times 10^{-4} \pm 9.7 \times 10^{-6}$
I.8	1.05	0.10	2	14895 ± 617	0.992	$1.4 \times 10^{-4} \pm 6.0 \times 10^{-6}$
I.9	1.05	0.20	2	15143 ± 566	0.983	$7.3 \times 10^{-5} \pm 1.8 \times 10^{-6}$
II.1	0.1	0.02	2	16957 ± 1145	0.942	$8.2 \times 10^{-4} \pm 5.5 \times 10^{-5}$
II.2	0.1	0.02	1	14977 ± 876	0.954	$1.5 \times 10^{-3} \pm 8.5 \times 10^{-5}$
II.3	1.05	0.02	1	12102 ± 481	0.981	$1.1 \times 10^{-3} \pm 4.6 \times 10^{-5}$
II.4	2.0	0.02	2	15421 ± 1194	0.985	$7.4 \times 10^{-4} \pm 5.7 \times 10^{-5}$
II.5	2.0	0.02	1	12664 ± 718	0.978	$1.2 \times 10^{-3} \pm 6.9 \times 10^{-5}$
II.6	10.5	0.02	2	23612 ± 589	0.886	$1.1 \times 10^{-3} \pm 1.1 \times 10^{-5}$
II.7	10.5	0.02	1	22603 ± 402	0.972	$2.1 \times 10^{-3} \pm 3.8 \times 10^{-5}$

[a] No. I.1−I.9 summarize the effect of flow velocity; No. II.1−II.7 summarize the effect of colloid size and collector size.



* η_{0exp}—E

Figure 2. Effect of flow velocity on single-collector contact efficiency.

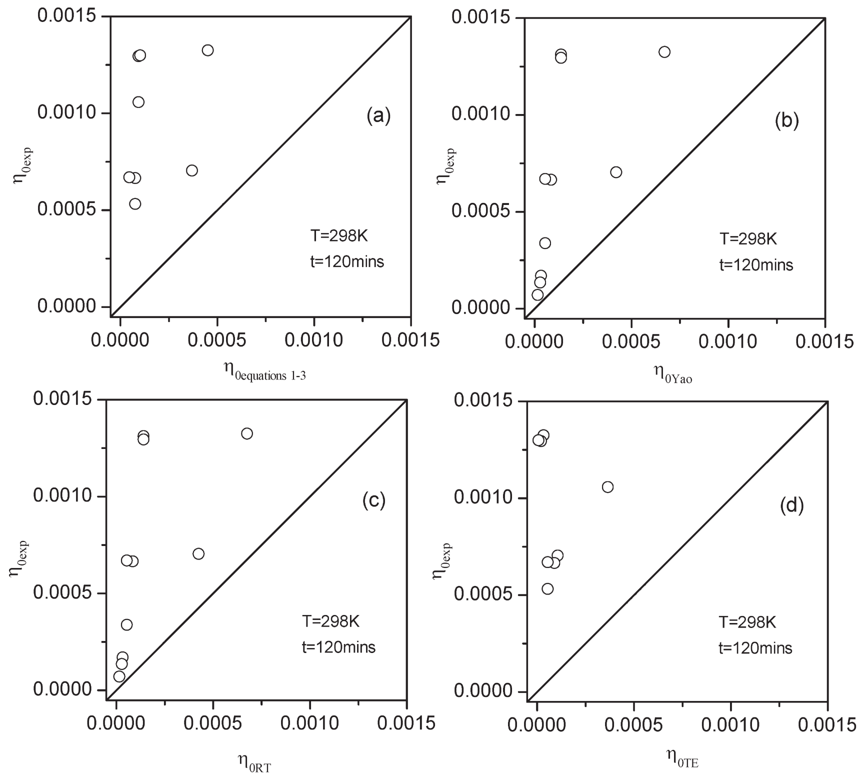


* η_{0exp}—η_0-experimental

Figure 3. Effect of colloid and collector sizes on single-collector contact efficiency.

contact efficiency and the colloid approach velocity. This trend is consistent with the findings of previous studies on colloid transport in porous media (spherical collectors). A number of experimental and modeling studies have demonstrated that the filtration/removal rate of colloids through a porous medium filter decreases when the flow rate increases.[35−37] Compere et al.[37] observed that the deposition rate of clay colloids decreases with flow velocity, whereas the collector efficiency increases by a factor of 5.1 as flow velocity decreases by a factor of 0.11. Similarly, Camesano and Logan[36] observed that, for passive colloids, the fractional retention would increase by more than 800% as the pore velocity was decreased from 120 to 0.56 m/day. For suspended sediments captured by a cylinder collector, however, Palmer et al[24] observed an opposite result showing the increases of contact efficiency with higher flow rates. This divergence might be attributed to the high settling/sedimentation rate of suspended sediments in the overland flow, which is much higher than that of colloids (negligible in this work). In the study of Palmer et al.,[24] increasing in flow rate could offset the sedimentation processes and increase the capture rate of sediments by the cylinder collector, and thus increase the single-collector contact efficiency.

For collectors of different sizes (i.e., d_c = 1 or 2 cm), the single-collector efficiency (η_0) varied with colloid diameters (d_p), suggesting that a minimum value of η_0 might exist for a colloid size (Figure 3). This is consistent with the classic single-collector



* η_{0exp}—η_0-experimental; $\eta_{0equations1\text{-}3}$—$\eta_0$-equations 1-3; η_{0Yao}—η_0-Yao; η_{0RT}—η_0-RT; η_{0TE}—η_0-TE

Figure 4. Comparison of experimental data of single-collector contact efficiency with predictions of (a) eqs 1−3, (b) the YAO model, (c) the RT model, and (d) the TE model. Symbols are experimental data and solid line is the 1:1 line.

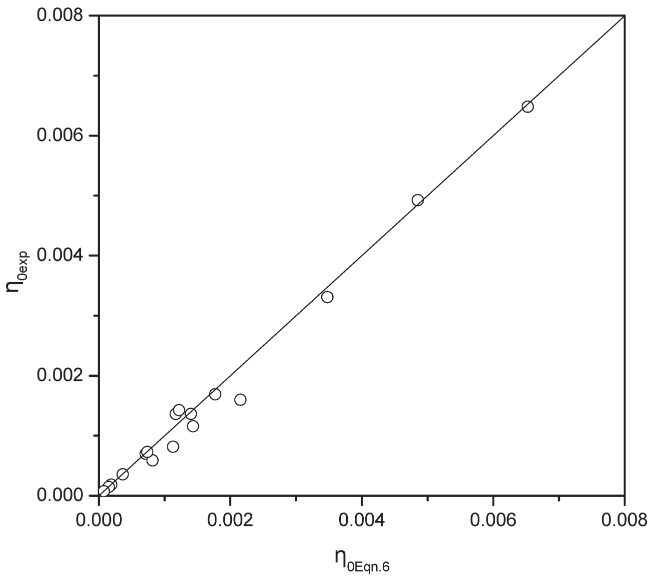
efficiency theory of colloid filtration in porous media.[26] For colloid transport in porous media under unfavorable conditions, Elimelech [38] found that particles with diameter of 1.15 μm had a lower collector efficiency than particles with diameters of 0.08, 0.17, or 2.52 μm. In a test of colloids with a wide range of particle sizes, Zhuang et al. [39] found that dependence of colloid retention on particle size was nonlinear and there existed a fraction of colloids with greater mobility (i.e., minimum value of η_0) than other fractions. However, several studies have also observed the independence of collector efficiency on particle size.[40,41] Further investigations are still needed to quantify the relationship between colloid size and collector efficiency.

Comparisons of the η_0 values between the two collectors of different sizes also revealed that, for the same u and d_p, the smaller collector (i.e., 1 cm) had higher values of η_0 than the larger collector (i.e., 2 cm). Similar relationship between η_0 and d_c was observed for the removal of suspended sediments by cylinder collectors in overland flow.[24]

Comparison of Experimental Data and Theoretical Predictions. The experimental data discussed above were compared with their corresponding values of η_0 based on the theoretical predications of suspended particles captured by a cylinder collector in creeping flow (i.e., eqs 1−3). Under shallow overland flow conditions, average overland flow velocity is often used to determine the single-collector contact efficiency at a cross section of the cylinder (two-dimensional).[24] As a result, mathematical formualtions of the single-collector contact efficiency on colloid transport in porous media, such as the Yao model,[26] RT model,[27] and TE model[29] can be also used to calculate the theoretical predications of colloids captured by a cylindrical collector.

For all conditions tested, the experimental single-collector contact efficiencies were larger than the corresponding theoretical values of eqs 1−3 (Figure 4a). This discrepancy is probably due to the relatively high collector Reynolds numbers in the experiments. Although the experimental flow velocities were controlled to be low, the Re_c was between 0.4 and 40 (laminar flow), across the limit of eqs 1−3 ($Re_c < 1$, creeping flow). Under creeping flow conditions, it is reasonable to assume that only interception and diffusion processes are the main contributors to the single-collector contact efficiency. When the Re_c is higher, however, other processes, such as dispersion, could also alter the contact of colloids to the collector. A number of studies of the transport of colloids and other suspended particles in aquatic systems have emphasized the importance of longitudinal and vertical dispersion on their removal by vegetation.[17,42,43] Similarly, the sphere collector models also underestimated the experimental η_0 for all of the experimental conditions (Figure 4b−d). The failures of the theoretical predictions suggested that none of the existing equations/models of single collator efficiency could be applied directly to determine the filtration rate of colloidal particles by dense, nonsubmerged vegetation in laminar overland flow.

A Regression Equation. Our experimental data indicated that the actual single-collector contact efficiency should be a function of the flow velocity, collector size, and colloid size. Therefore, a regression equation in the form of $\eta_0 \approx a\ (Re_c)^b (N_{Pe})^c$ can be formulated, where N_{pe} is the Peclet number ($N_{pe} = ud_c/D$). On the basis of the experimental data obtained (Re_c =0.42−42 and N_{Pe} = 4.5 × 10^5 − 9.7 × 10^7), the best-fit (R^2 > 0.98, Figure 5)



* η_{0exp}—η_0-experimental; $\eta_{0Eqn.6}$—η_0-Equation 6

Figure 5. Comparison of experimental data of single-collector contact efficiency with predictions of the regression equation (eq 6). Symbols are experimental data and solid line is the 1:1 line.

regression equation can be written as follows:

$$\eta_0 = 0.0044\text{Re}_c^{-0.94} N_{\text{Pe}}^{-0.03} \quad (6)$$

This regression equation is less sensitive to the Peclet number than to the Reynolds number, but the Peclet number term ($N_{\text{Pe}}^{-0.03}$) is needed to represent the effect of colloid size on the single-collector efficiency.

Although the regression equation can be applied to a wide range of Peclet numbers (two orders), it is only valid for predicting the single-collector contact efficiency of colloids approaching cylindrical collectors under laminar flow conditions. It was not possible to further validate the regression equation for field conditions because only few/no studies have been conducted to measure the removal of colloidal particles by plant stems in laminar overland flow. In a recent study, Huang et al. [17] measured the filtration of 1 μm latex microspheres within emergent vegetation at a wetland field site located in the Florida Everglades. They found that plant stems could effectively remove the colloids (microspheres) from flow and the average single collector removal efficiency was 0.002. Unfortunately, the Re_c value of Huang et al. [17] was above the limits of the regression equation, and it could not be applied to their experiment. Additional investigations, particularly experimental studies, are in critical need to measure the removal of colloids by plant stems in laminar overland flow.

Although its generality still needs to be tested, the regression equation can be used to determine the colloid filtration/deposition rate in dense, nonsubmerged vegetation (e.g., grasslands and vegetative filter strips) in laminar overland flow, and to enhance current capacity to predict the fate and transport of colloidal contaminants in surface runoff. For colloid removal by emergent vegetation in laminar overland flow, the single-collector removal efficiency (η) is often lower than the single-collector contact efficiency (η_0) because the contacts between colloids and stems may not guarantee 100% removal. Therefore, single collector removal efficiency is often expressed as a product of an empirical attachment (collision) efficiency (α) and the single-collector contact efficiency:[26]

$$\eta = \alpha\eta_0 \quad (7)$$

The attachment efficiency is defined as the fraction of contacts between colloids and the collector that result in attachment, which reflects the chemistry of the system.[26] Several theoretical formulations have been established to calculate α based on the Derjaguin−Landau−Verwey−Overbeek (DLVO) interaction energy profiles between colloids and the collector upon close separation.[44−46]

For colloids in overland flow, convection-dispersion equations coupled with deposition kinetics are commonly used to predict their fate and transport in dense vegetation.[47] The kinetic deposition rate is often represented by the particle deposition rate coefficient, k_d.[26,29] For a vegetation system of a spacing density (f), which is defined as the ratio of the empty area among the plant stems divided by the total vegetated area, the relationship between k_d and η can be written as follows:

$$k_d = \frac{4(1-f)}{\pi d_c}\frac{u}{f}\eta \quad (8)$$

where the ratio of the approach velocity to the spacing density (u/f) is the interstitial fluid velocity commonly used in modeling colloid transport in filter media.

■ ENVIRONMENTAL IMPLICATIONS

For the first time, laboratory experiments were conducted to measure the single-collector contact efficiency of colloids by cylindrical collectors in a flow chamber under laminar flow conditions. Our results indicated that η_0 decreased with flow velocity (u) and collector diameter (d_c), and a minimum value of η_0 might exist for a colloid size (d_p). Because existing single-collector contact efficiency models underestimated the η_0 of colloid capture by the cylinders in laminar overland flow, a regression equation was thus derived from experimental data. Findings from this work can help advance current understanding of the fundamental processes that govern colloid fate and transport in overland flow in surface vegetation systems. They can also inform guidelines for the design, establishment, and maintenance of surface vegetation as filters for colloidal contaminants, such as pathogens. Because establishment of dense vegetated areas in the form of grass filters is a low-cost and potentially effective pollution control practice, optimization of the design and implementation of these filters can produce significant societal and environmental benefits.

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