Journal of Environmental Management 166 (2016) 450–456

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Short communication

Flocculated sediments can reduce the size of sediment basin at construction sites

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ARTICLE INFO

Article history:
Received 31 May 2015
Received in revised form
24 October 2015
Accepted 28 October 2015
Available online xxx

Keywords:
Flocculation
Polyacrylamide
Sediment basin
Settling velocity
Total suspended solids

ABSTRACT

Due to stringent water quality regulations on stormwater discharges, there is increasing interest in chemically-assisted settling of suspended sediments at construction sites. This study investigated settling characteristics of flocculated sediment by polyacrylamide (PAM) in a top-loading settling tube. Studied sediment materials were obtained from construction sites in North Carolina, USA: Coastal Plain loamy sand (CPLS), Piedmont sandy clay loam (PSCL), Piedmont silt loam (PSL), and Mountain clay loam (MCL). The four different sediment suspensions mixed with and without dissolved PAM were introduced to the top of the column individually. During a 1-h settling period, samples were taken at 1-m depth from surface at various times and analyzed for total suspended solids (TSS). Flocculated sediment by PAM greatly increased its settled TSS fraction up to 95–97% only in 1-min settling period compared to those of unflocculated sediment (16–72%). The settling improvement by PAM was profound in the finer-textured soils (PSL and MCL) by increasing their median particle settling velocity (>2 cm s^{-1}) compared to unflocculated counterparts (<1.1 cm s^{-1}). Estimated surface area requirement of sediment basin suggested that the basins receiving flocculated sediment could be reduced in size (surface area) by 2- to 4-times compared to those receiving unflocculated sediment. Our results suggests that current sediment basin design could be modified when chemically-assisted settling is implemented, taking up less space and cost in construction sites.

1. Introduction

Turbidity in water exiting sediment basins is often in the range from 100 to 1000 nephelometric turbidity units (NTU) because fine suspended particles are so slow to be settled by gravity alone (Line and White, 2001; McCaleb and McLaughlin, 2008). Two management options may be taken to capture the fine suspended particles: (1) increasing the size of the basin to increase retention time and/or (2) adding flocculants to promote aggregation with a resultant increase in settling velocity. Option 1 may not be viable as it takes more space and cost, and very large basins would be needed for the smaller particles to settle. Option 2 has been demonstrated to be successful in reducing turbidity in construction site runoff (McLaughlin et al., 2009; Kang et al., 2013).

Flocculants are widely used in the wastewater and drinking water treatment for the removal of suspended solids. They have also been used to reduce erosion and sediment transport in agricultural fields and construction sites (Sojka et al., 2007; Babcock and McLaughlin, 2011). Polyacrylamide (PAM) is a class of synthetic polymer which can vary by net charge, charge density, and molecular weight (Seybold, 1994). High molecular weight (12–15 Mg mol^{-1}), moderately anionic-charged (10–20 mol %) PAMs are the most common in soil applications (Sojka et al., 2007). The primary functions of PAM are twofold: (i) a flocculating agent for suspended materials in aqueous suspension and (ii) an aggregating agent to stabilize soil structure. Small dosages of PAM into sediment suspension can gather and aggregate small masses into larger masses called flocs, thus enhancing the settling of suspended particles (Guibai and Gregory, 1991). Droppo et al. (2008) studied the effect of PAM, chitosan, and alum on settling velocity of a Canadian harbor bed sediment and found that the PAM produced the largest flocs with the highest settling velocity at the tested shear stresses. In a rainfall simulation study using a clay loam of North Carolina (NC), Kang et al. (2014a) found that runoff sediment

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http://dx.doi.org/10.1016/j.jenvman.2015.10.049
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treated with PAM had 7- to 9-times greater median particle diameter than untreated runoff sediment.

The effectiveness of PAM is affected by the characteristics of the soil material being treated. In general, fine fraction of soil (clay and silt) interacts with PAM primarily through the polymer bridging mechanism (Seybold, 1994; Nasser and James, 2006). In flocculation tests of various soils across NC, McLaughlin and Bartholomew (2007) found that soil texture, mineralogy, and extractable Fe were highly correlated with the flocculation efficacy by anionic PAMs. In their study, soils with kaolinitic mineralogy were more readily flocculated by the PAMs than those with smectitic mineralogy. Laird (1997) demonstrated that the efficacy of anionic PAM for clay flocculation varies with mineralogy (kaolinite > illite > quartz). The adsorption of PAM to quartz was poor due to lack of aluminol (>Al—OH) and silanol (Si—OH) groups, which are present on lateral edges of kaolinite and illite (Laird, 1997; Nasser and James, 2006).

The enhanced settling of suspended particles by flocculation may allow sediment basins to be reduced in size (i.e. surface area). Previous studies have demonstrated that retention time for flocculated sediment can be reduced when pumping turbid water into settling basins (Bhardwaj and McLaughlin, 2008). The benefits of smaller basins at construction sites include lower installation costs, less land area used, and easier maintenance. The objectives of this study were 1) to investigate the settling characteristics of flocculated sediment in representative NC construction site soils and 2) to determine potential changes in the basin size as a result of PAM treatment.

2. Materials and methods

2.1. Settling tube experiment

A total of 16 settling tube tests were performed as a combination of four soil materials and two PAM levels (unflocculated and flocculated) in duplicate. The soil materials (mostly subsoils) were collected from construction sites, representing major geographical regions of NC (Coastal Plain, Piedmont, and Mountain regions) (Table 1). All the soil materials were air-dried and passed through a 2-mm sieve.

We constructed a 1.25-m tall by 10-cm diameter clear plastic tube installed with two outlets: an upper sampling port located at 15 cm from the bottom and a bottom sampling port (Fig. 1a). We filled the tube with tap water up to a height of 1 m as measured from the upper sampling port. We prepared the sediment suspension by weighing 20 g of air-dried soil and mixing it with 150 mL of tap water for 30 s. Flocculation was achieved using an anionic PAM (APS 705 Silt Stop, Applied Polymer Systems, Inc., Woodstock, GA), which contains a proprietary mixture of medium- and high-molecular weight anionic PAM and is certified by North Carolina Department of Environment and Natural Resources (NCDENR) for stormwater treatment. To flocculate the sediment, 1 mL of dissolved PAM (0.5 g L^{-1}) was added to the suspension, resulting in a PAM concentration of 3.3 mg L^{-1} which was within the optimal PAM doses in flocculating the study soils (McLaughlin and Bartholomew, 2007). Flocculated (PAM) or unflocculated (no PAM) sediment suspension was added to the top of the tube through a conical sample dissipater. The dissipater distributed the suspension evenly at the top of the water column with minimal turbulence. Once settling was initiated, we obtained samples (50–80 mL per sample) at the upper sampling port at 0.25, 0.5, 0.75, 1, 2, 3, 4, 5, 10, 15, 30, and 60 min. After the final sampling at 60 min, the settled sediment was carefully removed through the bottom drainage port. For the collected samples, total suspended solids (TSS) concentration was determined gravimetrically by filtering through 76-mm fiberglass filters (Environmental Express, Mt. Pleasant, SC) and drying for 24 h at 105 °C (Clesceri et al., 2012). Subsequent data analysis steps after measuring TSS concentrations is presented in Fig. 2.

Table 1
Selected properties of Coastal Plain loamy sand (CPLS), Piedmont sandy clay loam (PSCL), Piedmont silt loam (PSL), and Mountain clay loam (MCL).

Property	Soil material			
	CPLS	PSCL	PSL	MCL
pH[a]	4.4	5.3	4.4	4.5
Sand[b] (g kg^{-1})	811	575	180	440
Silt[b] (g kg^{-1})	140	164	568	277
Clay[b] (g kg^{-1})	49	261	252	283
Organic matter[c] (g kg^{-1})	2.8	8.6	5.9	9.7

[a] pH by a glass electrode at soil-to-solution ratio.
[b] Particle size analysis by hydrometer method.
[c] Organic matter by loss-on-ignition.

2.2. Settling velocity distribution curve

The presentation of settling data in this study was based on the type I settling, which assumes discrete particle settling (i.e., particles fall independently of each other) in low-concentration solutions (Syvitski et al., 1991; Haan et al., 1994). We assumed our premixed sediment suspensions did not contribute to further flocculation during the settling process and were not hindered by other settling particles. The TSS concentrations sampled at various sampling times were compared to the initial TSS and the mass fraction of particles removed from the water column was calculated as a function of sampling duration (Fig. 2). In theory, samples withdrawn from the sampling port at times ($t_1, t_2, t_3, \ldots, t_n$) represent the settled solids along the length of the settling tube (H) between time t_{n-1} and t_n. The settling velocity for each sampling period (V_n, L T^{-1}) was computed by:

$$V_n = H/(t_n - t_{n-1}) \tag{1}$$

The smallest particle that was placed at the surface and reached at the bottom of the column with given time (t_o) has a settling velocity of V_o (Fig. 1b):

$$V_o = H_o/t_o \tag{2}$$

where H_o is distance traveled (L) and t_o is time of travel (T). All particles with a settling velocity greater than V_o will be 100% removed from the water column. Another particle placed at distance H_1, with a settling velocity (V_1) less than V_o but the same travel time to the sampling port (t_o), has a settling velocity of:

$$V_1 = H_1/t_o \tag{3}$$

By rearranging Eqs. (2) and (3) in terms of t_o,

$$t_o = H_o/V_o = H_1/V_1 \tag{4}$$

A large variation in particle size exists in a typical suspension of soil particles (Reynolds and Richards, 1996). The mass fraction of particles (F) with a settling velocity of V_1 less than V_o, which will arrive or pass the sampling port in time t_o, is computed by:

$$F = H_1/H_o = V_1/V_o \tag{5}$$

An informative way of displaying the settling tube data is to construct a settling velocity distribution curve (Wong and Piedrahita, 2000). The X-axis of the curve is the settling velocity (V) and the Y-axis is the fraction of particles that has a settling