TECHNICAL NOTE:

EFFECT OF FLUSHING VELOCITY AND FLUSHING DURATION ON SEDIMENT TRANSPORT IN MICROIRRIGATION DRIPLINES

J. Puig-Bargués, F. R. Lamm

ABSTRACT. *Dripline flushing is a maintenance procedure that is recommended for all microirrigation systems. However, flushing velocity and flushing duration, which particularly affect the design and management of subsurface drip irrigation (SDI) systems, have not been studied extensively. For a better understanding of the flushing process in driplines and manifolds, a laboratory study was conducted at Kansas State University with a 10 m transparent pipe simulating an SDI dripline. Three different sediments with sizes up to 500 μm were introduced into the pipeline, and their distribution along the pipeline was analyzed under different flushing velocities over various times. Head loss under the conditions of this study increased exponentially with increased flushing velocity, suggesting that the flow regimes could be characterized between moving beds and heterogeneous flow. The percentage of pipeline blockage was logarithmically related to the flushing velocity, with greater than 30% of the pipeline occupied by larger sand sediments when the flushing velocity was less than 0.3 m s^{-1}. Although flushing velocities at or near the calculated deposition velocity could remove the majority of the sediments with a short duration of 15 min or less, flushing velocities that were approximately 45% to 65% of the deposition velocity could achieve similar sediment removal with longer flushing duration (up to 180 min). The ASAE EP-405 recommended minimum flushing velocity of 0.3 m s^{-1} still appears adequate for most microirrigation systems operating under typical conditions. Designers are encouraged to calculate the deposition velocity for new microirrigation systems and to use it as a flexible guideline to assess the adequacy of flushing. End-users are encouraged to extend the duration of flushing for perhaps as long as 5 min after the initial concentration of sediments are removed to improve overall flushing. Further research is warranted to evaluate flushing velocity, but the results of this study should be representatively instructive of the phenomenon of sediment transport in microirrigation driplines during flushing.*

Keywords. *Drip irrigation, Dripline flushing, Emitter clogging, Microirrigation, Pipeline sedimentation.*

Dripline flushing is a maintenance practice for microirrigation systems that removes particles not retained by the microirrigation system filters and that accumulate in the driplines (Adin and Sacks, 1991; Ravina et al., 1992). These particles may travel through the filters as individual particles, but they then flocculate or become attached to organic residues and eventually become large enough to clog emitters (Nakayama et al., 2007). Dripline flushing also allows removal of soil particles that may have been backsiphoned through the emitters during system stops, as well as chemical precipitates and biofilms that may have formed. For these reasons, dripline flushing is an essential practice to properly maintain subsurface drip irrigation (SDI) systems and ensure a long system life (Lamm and Camp, 2007).

To be effective, dripline flushing must be done often enough and at an appropriate velocity to dislodge and transport the accumulated sediments (Nakayama et al., 2007). The flushing velocity is of critical importance for sediment and contaminant removal and has technical and economic effects, since the microirrigation system must be designed with the requirements for achieving an appropriate flushing velocity. Thus, SDI system design should be influenced by the flushing velocity at which contaminant removal occurs, since lateral lengths, operating pressures during flushing, and dripline diameters will be affected (Lamm and Camp, 2007). ASAE Engineering Practice EP-405 recommends a minimum flushing velocity of 0.3 m s^{-1} (*ASAE Standards*, 2003), but some researchers have suggested that a flushing velocity of 0.5 to 0.6 m s^{-1} may be necessary when larger particle sizes need to be discharged, such as when coarser filters are used (Hills and Brenes, 2001; Nakayama et al., 2007) or when larger diameter driplines are used (Koegelenberg, 1998). In a short-term study with target flushing velocities ranging from 0.23 to 0.61 m s^{-1}, Puig-Bargués et al. (2010b) did not find large effects of flushing velocity on emitter discharge. However, greater flushing velocities removed more solids from the driplines. Puig-Bargués et al. (2010b) also found that the pattern of sediment deposition within the flushed driplines was different from that of the non-flushed driplines. Greater deposition near the dripline inlets was observed for the

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flushed driplines with smaller flushing velocities, and greater solids deposition closer to the distal ends was observed when the flushing velocity was greater.

Different flushing frequencies have been used by several researchers, including daily (Ravina et al., 1997), twice per week (Tajrishy et al., 1994), once per week (Tajrishy et al., 1994; Hills et al., 2000), every two weeks (Ravina et al., 1997; Hills and Brenes, 2001; Puig-Bargués et al., 2010b), monthly (Puig-Bargués et al., 2010a, 2010b), and seasonal (Puig-Bargués et al., 2010a). Puig-Bargués et al. (2010a) found greater emitter clogging at the distal end of the dripline without flushing than with a monthly and a seasonal flushing, with the latter two being not significantly different. Conversely, Puig-Bargués et al. (2010b) observed an inconsistent effect of flushing frequency on dripline sediment removal. There was a greater sediment removal for a single flushing at the greatest flushing velocity, but as flushing velocity decreased, there tended to be slightly better sediment removal with more frequent flushing. Differences in localized flushing velocities at the sediment deposition points within the dripline and the erosive effects of the particle aggregates may have affected sediment movement.

After studying the effect of different flushing velocities and frequencies, Puig-Bargués et al. (2010b) suggested that increasing the duration of flushing could be a more important and less expensive means (i.e., increased flushing events increase labor requirements, and greater flushing velocities can greatly increase SDI system costs through different pumping requirements and reduced zone size, creating a need for more pipes, controls, and connectors) of increasing the overall effectiveness of flushing, given the manner in which sediments move within the dripline during flushing.

The main objectives of this work were to study the effect of flushing velocity and flushing duration on sediment transport in a pipeline that was used to simulate an SDI dripline.

Material and Methods

Experimental Setup

An experimental setup simulating a dripline was constructed in a laboratory at the Kansas State University Northwest Research-Extension Center in Colby, Kansas. The setup (fig. 1) consisted of a horizontal transparent PVC pipe of 25.4 mm internal diameter, 3.8 mm wall thickness, and 10 m in length, connected to a vertical valved flushline riser pipe (1 m height) of the same internal diameter. After this vertical pipe, the water was gravimetrically discharged into a 200 L storage tank for recirculation into the system. Water temperature was measured in this tank using a liquid thermometer (±0.1°C precision). At the water storage tank outlet, the water was filtered by a 75 µm disk filter before being pumped into the system. The water was pumped through the system to the beginning of the experimental pipe through an opaque PVC pipe of 50 mm internal diameter.

A volumetric flowmeter was installed to determine the volume and velocity of the circulating water. Pressure gauges located at the beginning and end of the transparent experimental horizontal pipe were used to measure the head loss. A gate valve near the pipeline inlet was used for regulating the flow rate and water velocity. A small solid dosing tank, which was pressurized, was used for releasing the sediments into the system.

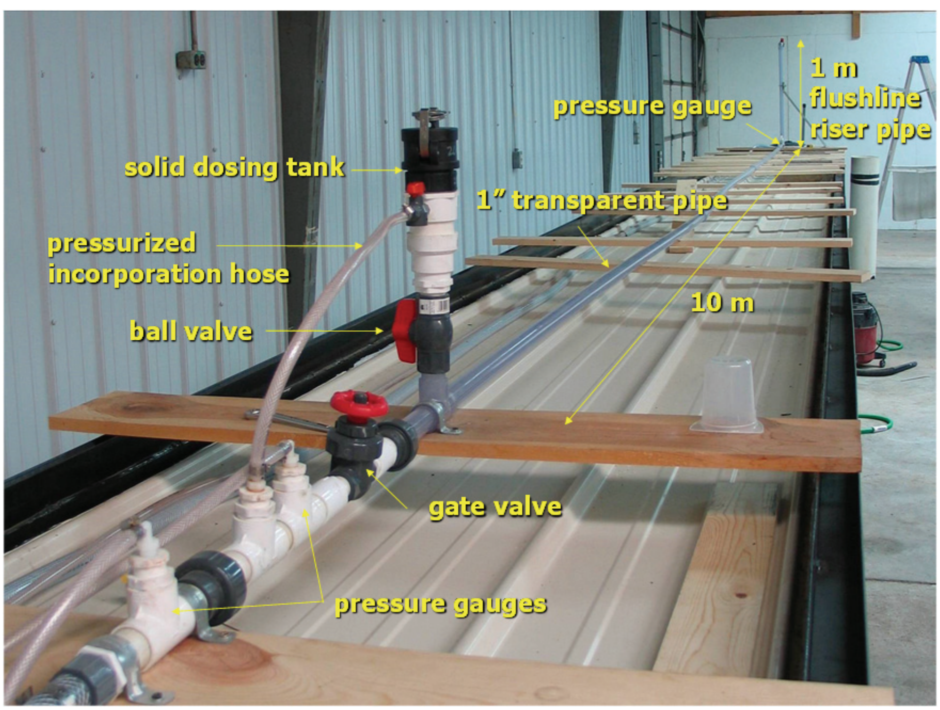

Figure 1. Experimental setup for the study. The water storage tank, pump, and transport pipe are located below the raised platform.

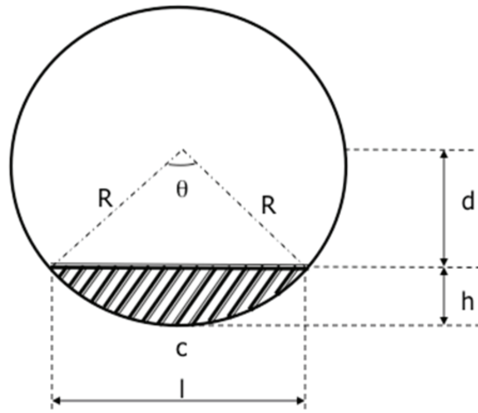

Figure 2. Schematic of a pipeline with a sediment bed.

EXPERIMENTAL PROCEDURE

Determination of Head Loss and Pipeline Cross-Sectional Area Occupied by Sediments

The goal of the first experiment was to determine the head loss in the system as well as the area occupied by the sediments. Different water flow rates and velocities were obtained by opening or closing the gate valve preceding the transparent pipe inlet (fig. 1). When the water flow rate and velocity reached a stable value, 300 g of sediments, which had been previously placed in the small solid dosing tank, were released into the pipeline by opening the ball valve and introducing a small amount of pressurized water above the sediments. The sediments entered the transparent pipeline in less than 30 s, bringing the volumetric concentration of the sediments in the pipeline to an arbitrary value of approximately 2%. The pipeline remained under constant pressure during this process. Overall, three types of solids were used in the various experiments: aluminum oxide with a size below 250 µm, silica sand with a size below 250 µm, and silica sand with a size between 250 and 500 µm. Sediments of two densities (silica sand at 2650 kg m^{-3} and aluminum oxide at 3960 kg m^{-3}) were used to assess if there were differences in sediment dynamics within the pipeline during flushing. The solids were previously sieved on a sieve stack to obtain the desired size range. Additionally, a trial was conducted using only water to determine the pipeline head loss without sediments.

At regular intervals, the head loss between the beginning and end of the transparent pipe was determined by comparing the pressure gauges. The pumped volume of water was recorded from the volumetric flowmeter. The water velocity was determined by dividing the pumped volume by the elapsed time and the pipeline cross-sectional area. The sediment bed height *h* in the lateral (fig. 2) was measured externally with a measured rule in 1 m increments along the pipeline once the pump was switched off for assurance of accurate height readings.

Once the sediment bed height *h* (m) was measured, the pipeline cross-sectional area occupied with sediments (A_f, m^2) was computed with the formula:

$$A_f = R^2 \cdot \cos^{-1}\left(\frac{R-h}{R}\right) - (R-h)\sqrt{2Rh-h^2} \tag{1}$$

where *R* is the pipeline radius (m). The percentage of cross-sectional area filled with sediments was obtained dividing A_f by the total pipeline cross-sectional area.

The experimental conditions for the different runs and sediments used are listed in table 1. The Reynolds number (Re) was computed using the formula:

$$\mathrm{Re} = \frac{\rho v D}{\mu} \tag{2}$$

where ρ is the water density (kg m^{-3}), *v* is the water velocity across the pipe (m s^{-1}), *D* is the internal diameter (m), and µ is the water viscosity (Pa s).

Pipeline flushing can be considered as a case of solid transport in liquids. There are four flow regimes for the solid transport in liquids: homogeneous suspension, heterogeneous suspension, moving bed, and stationary bed (Abulnaga, 2002). The transition point between the heterogeneous suspension and the moving bed regimes is characterized by the deposition velocity v_D. When driplines are not flushed at velocities greater than v_D, contaminant particles will move much more slowly through the SDI system, which may increase potential for emitter clogging. The deposition particle velocity v_D (m s^{-1}) was calculated with the Durand and Condolios (1952) equation:

$$v_D = F_L \sqrt{2\, g\, D_i \left(\frac{\rho_s - \rho_L}{\rho_L}\right)} \tag{3}$$

where F_L is the Durand factor (dimensionless), *g* is the gravity acceleration (m s^{-2}), D_i is the pipeline internal diameter (m), ρ_s is the particle density (kg m^{-3}), and ρ_L is the liquid density (kg m^{-3}). The Durand factor (F_L) can be computed as (Schiller and Herbich, 1991):

$$F_L = 1.3\, C_v^{\,0.125}\, (1 - e^{-6.9\, d_{50}}) \tag{4}$$

where C_v is the particle volume concentration, and d_{50} is the particle diameter below which 50% of the particles are smaller (mm).

The particle density of the silica sand was considered to be 2650 kg m^{-3}, and the aluminum oxide was considered to be 3960 kg m^{-3}.

Table 1. Experimental conditions for the experiments carried out for determining the head loss and the area occupied by the sediments.

Type of Sediment	Number of Different Experimental Points	Head Loss Range (kPa)	Velocity Range (m s^{-1})	Reynolds Number Range[a]
None	14	0.7 to 37.2	0.12 to 0.61	3175 to 15554
Aluminum oxide, <250 µm	18	9.7 to 70.3	0.06 to 0.54	1524 to 13868
Sand, <250 µm	44	4.1 to 39.0	0.08 to 0.62	1968 to 14831
Sand, 250-500 µm	64	3.1 to 48.3	0.04 to 0.64	946 to 15811

[a] At the experiment average temperature of 22.9°C.

Determination of Sediment Advance over Time within the Pipeline

A second experiment was carried out to analyze the effect of elapsed time on sediment transport within the pipeline. The procedure was similar to the experiment described in the previous section but used only the two sizes of silica sand. A 75 µm (200 mesh) filter cloth was placed below the vertical flushline riser outlet to strain the particles transported out of the pipeline by the water. Each run lasted until no sediments could be seen in the pipeline or for a maximum operation time of 180 min. When a run ended, the cloth filter was removed and replaced with a clean one. The pipeline inlet gate valve (fig. 1) was then opened to allow a higher flow rate for flushing the remaining sediments in the pipeline to be trapped by the new cloth. Both cloth filters were dried until a constant weight was reached, and the total sediment weights were determined based on the initial clean cloth filter weights. This procedure was used to determine the effectiveness of flushing. During the process, it was determined that the filter cloth did not retain some of the smaller sediments, but the errors were not great. These errors will be discussed later.

For these experiments, the water temperature at the storage tank was determined. These temperatures allowed calculating the water density and viscosity considering the water temperature with the following formulae, which were obtained by fitting the experimental data between 15°C and 35°C to quadratic equations (Weast, 1986):

$$\rho = -0.0047\,T^2 - 0.0169\,T + 1000.5 \qquad R^2 = 0.999 \tag{5}$$

$$\mu = 4\times10^{-7}T^2 - 4\times10^{-5}T + 0.0017 \qquad R^2 = 0.999 \tag{6}$$

where ρ is the water density (kg m^{-3}), µ is the water viscosity (Pa s), and T is the water temperature (°C) measured in the water storage tank during each run. The experimental conditions for the different runs and sediments used are detailed in table 2.

RESULTS AND DISCUSSION

HEAD LOSS AS RELATED TO WATER VELOCITY

The head loss per unit of pipeline length as a function of water velocity (fig. 3) was very similar for the two sizes of silica sand. Since the mass concentration was the same for the two silica sands, and the particle density was similar, there would be fewer overall particles of the larger sand, which helped to reduce differences in the head losses. In contrast, the head loss when using aluminum oxide was much greater, due primarily to its higher density. Exponential equations relating head loss per pipeline length versus water velocity were fitted (table 3). As the flow rate approaches zero, theoretically there should be large increases in pressure drop due to the flow regime changing from heterogeneous and moving bed flow to a stationary bed, where the pipe cross-sectional area begins to become more restricted. However, this was not observed in this experiment, probably because the concentration of solids was low and also probably because localized increases in water velocity in the vicinity of any bed formation quickly eroded the larger particle blockages. There are more formalized procedures in the literature for calculating head loss in slurry flows (Wasp et al., 1977; Abulnaga, 2002). These results are provided to illustrate that the presence of sediments can increase head loss within pipelines.

The deposition velocity (v_D) calculated with equation 3 was 0.42 m s^{-1} for the silica sand smaller than 250 µm and 0.56 m s^{-1} for the aluminum oxide smaller than 250 µm (d_{50}, median diameter of particles, assumed to be 125 µm). For the larger silica sand between 250 and 500 µm, the calculated v_D was 0.67 m s^{-1} (d_{50} assumed to be 375 µm). Below these velocities, the sediments moved slowly through the pipeline because the flow regime was a moving bed, as shown in figure 4. Particles remaining in driplines for a longer time period present a greater clogging hazard. These moving beds, which are analogous to the movement of sand dunes due to wind erosion, were also observed by Shannon et al. (1982) in a field microirrigation experiment using water from an irrigation canal.

Table 2. Experimental conditions for the runs with sand to determine sediment advance time.

Type of Sediment	Average Velocity (m s^{-1})	Average Flow Rate (m^3 h^{-1})	Temperature (°C)	Reynolds Number	Head Loss (kPa)	Total Operation Time (min)
Sand, <250 µm	0.16	0.29	25.2	4283	15.9	180
	0.23	0.41	22.6	5827	16.9	180
	0.27	0.49	26.2	7378	19.5	180
	0.27	0.49	23.3	6944	19.7	180
	0.31	0.56	23.0	7922	21.2	180
	0.34	0.63	18.2	7808	22.6	60
	0.38	0.69	21.1	9316	25.0	45
	0.46	0.84	21.6	11402	31.6	15
	0.54	0.98	23.5	13948	39.3	15
Sand, 250-500 µm	0.22	0.41	23.1	5634	19.3	180
	0.27	0.49	26.5	7423	18.8	180
	0.30	0.55	21.2	7371	19.3	180
	0.30	0.55	20.9	7322	19.3	60
	0.35	0.63	22.4	8829	23.1	60
	0.39	0.70	27.2	10873	26.2	25
	0.47	0.85	22.2	11804	32.2	15
	0.62	1.12	20.7	15065	45.9	5

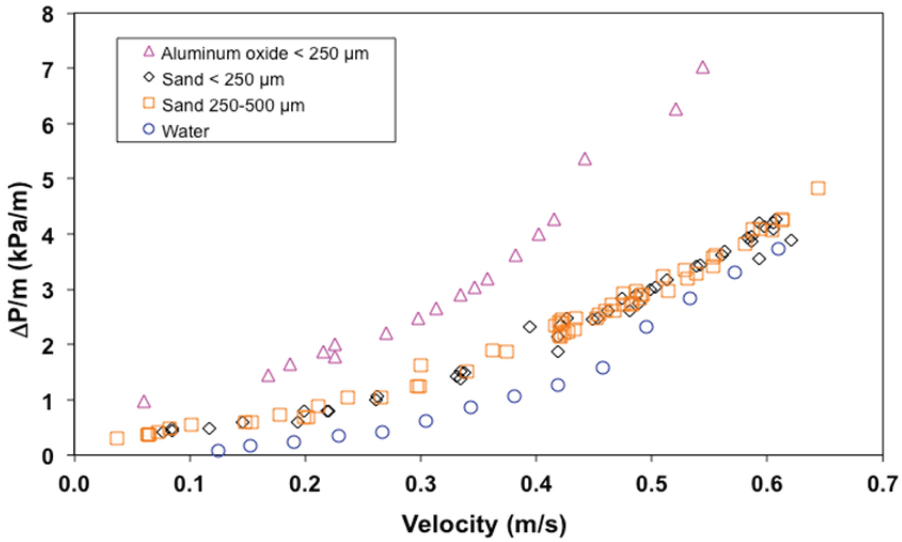

Figure 3. Head loss per pipeline length ($\Delta P/m$) as a function of water velocity and sediment type.

Table 3. Experimental equations relating head loss per unit length ($\Delta P/m$, kPa m^{-1}) with water velocity (v, m s^{-1}).

Type of Sediment	Equation	R^2
Water (no sediment)	$\Delta P/m = 0.0527e^{7.4735v}$	0.9622
Aluminum oxide, < 250 µm	$\Delta P/m = 0.7361e^{4.1827v}$	0.9924
Silica sand, <250 µm	$\Delta P/m = 0.3299e^{4.3526v}$	0.9834
Silica sand, 250-500 µm	$\Delta P/m = 0.3182e^{4.4703v}$	0.9844

Maximum Depth of Sediment Deposition within the Pipeline

The maximum deposition within the pipeline cross-section by the different materials is shown in figure 5. These values were obtained as the maximum height observed at any point within the pipe that occurred after the target velocity was reached. Logarithmic equations relating the maximum percentage of cross-sectional area filled with sediments and water velocity are shown in table 4. As it could be anticipated, the greater the water velocity, the less the cross-sectional area filled with sediments. The maximum cross-sectional area occupied by sediments was less than 30% for velocities between 0.46 and 0.64 m s^{-1}, which were greater than the deposition velocities (0.42 m s^{-1} for silica sand smaller than 250 µm and 0.56 m s^{-1} for aluminum oxide). For the smallest flushing velocities (below 0.1 m s^{-1}), for which the bed movement was very limited, the maximum cross-sectional area occupied by sediments was between 70% and 95%. These results reflect the influence of water velocity on the transport of sediments: the greater the maximum sediment bed height, the less the sediments are moved within the pipe. However, these results do not consider the effect of time nor the positions where the sediments were deposited within the pipeline, which will be discussed later.

Sediments Dynamics within the Pipeline

The sediment deposition and moving sediment beds demonstrated in figure 4 are further shown in figure 6. At the lowest water flushing velocities (0.16 and 0.23 m s^{-1}), the sediment deposits moved very slowly or almost not at all; as a result, nearly all of the sediment (>99%) remained in the pipeline even after 180 min of flushing (table 5). The algebraic closure error of sediments collected from the pipeline was not greater than 1.5% and is attributed to some very small particles were not retained by the filter cloth, as mentioned in the Experimental Procedures section. As the velocity increased above approximately 0.27 m s^{-1}, approximately 25% to 30% of the silica sand could be flushed from the pipeline after 3 h of pumping. The moving beds characterized in figure 6 emphasize that the flushing velocity was below the deposition velocity for these sizes of silica sand. However, at flushing velocities of approximately 0.46 m s^{-1} nearly 99% of both sizes of silica sand were flushed from the pipeline within 15 min of the initiation of flushing (table 5).

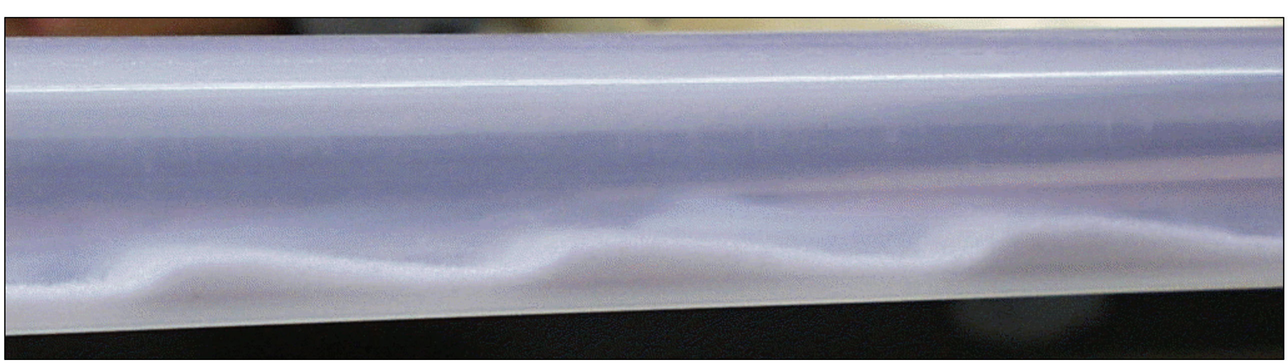

Figure 4. Slowly moving sediment bed observed when water velocity was below deposition velocity. Water flow was from right to left.

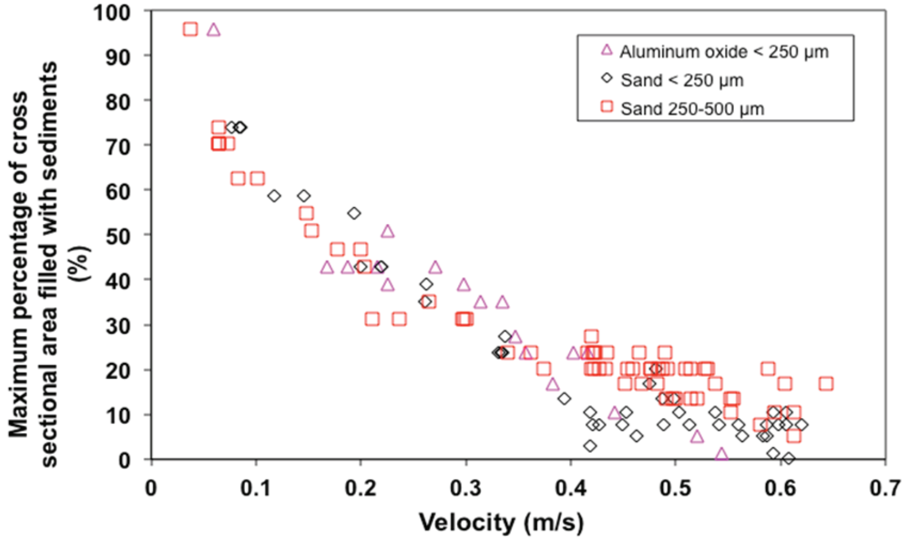

Figure 5. Maximum percentage of cross-sectional area filled by sediments as a function of water velocity and sediments.

Although the v_D for the smaller sand particles was calculated as 0.42 m s^{-1}, the v_D for the larger sand particles was calculated as 0.67 m s^{-1}, so flushing velocities below v_D can still be effective. This is probably because any increases in the sediment bed height leads to greater localized velocities (i.e., continuity equation, $Q = vA$), which will erode the bed and cause it to move farther downstream. The migrations of the sand particles farther downstream with time can be seen in figure 6 and were also reported by Shannon et al. (1982). This raises a question about what happens to these beds when they reach the flushline riser. In this laboratory setting, it was observed that deposits accumulating near the riser were also eroded and carried out of the pipeline, generally through the greater velocity at the center of the pipeline (data not shown). However, a similar question might be posed about removal of sediments that might be flushed from smaller driplines into a larger collector flushline. In this case, some sediment is likely to accumulate, based on equations 3 and 4, due to the much larger pipe diameter and might only be partially removed periodically by greater localized velocities as sediment begins to accumulate. However, the collector lines are reasonably large and should last many years. In addition, in terms of overall investment, the driplines are the most important component to protect. Examination of equations 3 and 4 suggests that different size driplines might have different flushing velocity requirements, as reported by Koegelenberg (1998). As dripline diameter increases, the deposition velocity also increases. Based on this study's results, it cannot be concluded that the values shown in table 6 are necessary for adequate flushing, but table 6 illustrates how dripline diameter and particle size can affect sediment dynamics. For typical filtration levels between 75 and 125 µm (d_{50} below these values), flushing velocities between 0.3 and 0.4 m s^{-1} are greater than the theoretical deposition velocity and should favor sediment removals from driplines. Driplines that have welded-on emitters or other appreciable intrusions into the water flow stream would have increased turbulence that would also likely increase movement of sediments, as reported by Shannon et al. (1982) for barbs intruding in the dripline. Another caveat to note is that in a real dripline with emitters that are discharging water, flushing velocities would be reduced with increased distance from the inlet. The velocity differences might result in different sediment transport regimes across the length of the dripline.

Table 4. Experimental equations relating maximum of cross-sectional area filled with sediment (A_f, %) with water velocity (v, m s^{-1}).

Type of Sediment	Equation	R^2
Aluminum oxide, <250 µm	Δ_f = -39.04ln(v) – 15.544	0.9163
Sand, <250 µm	Δ_f = -35.74ln(v) – 14.366	0.9464
Sand, 250-500 µm	Δ_f = -27.10ln(v) – 1.359	0.9655

When analyzing the advance of the two types of silica sand along the pipeline, it was found that at a velocity of 0.3 m s^{-1} and an elapsed time of 10 min, most of the particles did not reached the midway point of the pipeline, but there were differences in the occupation percentages by section (fig. 6). A flushing velocity of 0.30 m s^{-1} was able to remove most of the sand particles if the flushing event was extended as long as 180 min. At greater velocities, as the flow regime changes to a heterogeneous suspension and then to a homogeneous suspension, flushing times could be greatly reduced. A 5 min flushing duration was sufficient for removing most of the silica sand if the flushing velocity was 0.62 m s^{-1}. A flushing duration of 180 min or a flushing velocity of 0.62 m s^{-1} may not be practical. However, it should be noted that these sizes of silica sand sediments externally introduced into driplines would represent extreme conditions, not common in microirrigation practice. The clay particles that typically pass through microirrigation filter systems are typically <2 µm, and silt particles are between 2 and 50 µm (Nakayama et al., 2007), so the sediments in this study were much larger. As slow migration of bed particles likely exists in real microirrigation systems, end-users should extend the flushing duration perhaps as much as 5 min past the initial flush of sediments changing to clear water. This would allow for additional sediments to be flushed from the system. We have anecdotally observed additional amounts of sediment occurring after the initial clearing of the water on research SDI systems at the KSU Northwest Research-Extension Center.

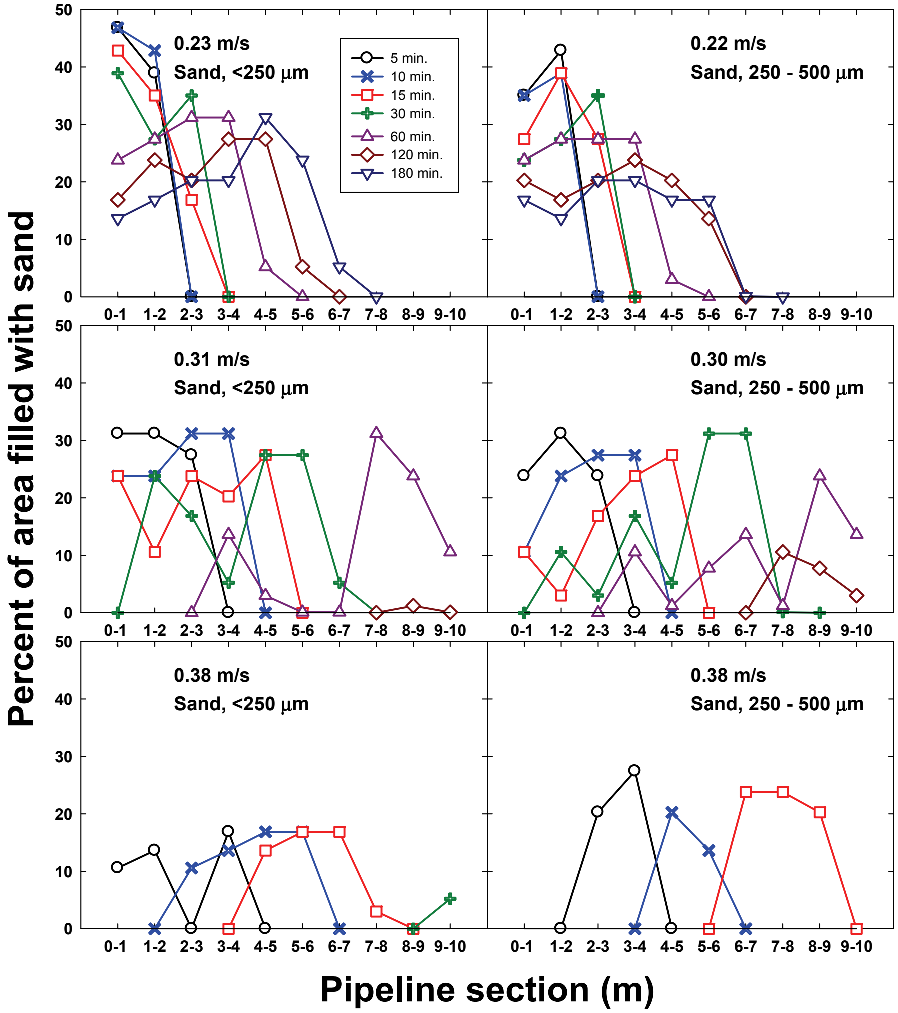

Figure 6. Percentage of cross-sectional area filled by sediments in each different sections of the pipeline as affected by water flushing velocity, size of silica sand particles, and the elapsed time since initiation of flushing. Missing symbols denote that no sedimentation was measured for that flushing velocity for that elapsed time period, meaning that most of the sediment had left the pipeline.

This study dealt only with inorganic particles. If microorganisms are present in irrigation water, (e.g., surface waters and reclaimed effluents), then more clogging is due to biofilm formation, which could also attach inorganic particles. Biofilms have their own dynamics, but their formation in driplines is mainly due to nutrients and suspended particles for velocities smaller than the velocity at which biofilm thickness reaches its maximum (0.45 m s^{-1}), whereas biofilm removal is due to hydraulic shear forces for velocities greater than deposition velocity (Li et al., 2012).

Table 5. Sand collected during the operation and after the final flushing for the runs with sand with a size below 250 µm.

Sediment	Average Velocity (m s^{-1})	Total Operation Time (min)	Sediment Collected (%) After Normal Operation	Sediment Collected (%) After Final Flushing	Sediment Collection Error (%)
Sand, <250 µm	0.16	180	0.0	99.6	0.4
	0.23	180	0.0	99.6	0.4
	0.27	180	74.2	24.7	1.1
	0.31	180	97.6	0.9	1.5
	0.34	60	97.1	2.4	0.5
	0.38	45	99.0	0.6	0.4
	0.46	15	98.9	0.6	0.5
	0.54	15	99.5	0.1	0.4
Sand, 250-500 µm	0.22	180	0.1	99.8	0.1
	0.27	180	67.2	32.4	0.4
	0.30	180	99.2	1.5	0.7
	0.30	60	38.3	61.7	0.0
	0.35	60	98.8	1.0	0.2
	0.38	25	98.9	0.0	1.1
	0.47	15	99.4	0.6	0.0
	0.62	5	99.4	0.0	0.6

CONCLUSIONS

This study analyzed the effect of flushing velocity and the time required for removing inorganic sediments from

Table 6. Deposition velocities (m s^{-1}) calculated by equations 3 and 4 for various dripline diameters and sediment d_{50} values assuming a particle density of 2650 kg m^{-3} and a volumetric solids concentration of 2%. The selected particle sizes are thought to be realistic values that might be encountered in typical microirrigation systems.

Dripline Internal Diameter (mm)	Median Sediment Particle Diameter (d_{50}, µm) 25	50	75	100	125	150
15.9	0.09	0.17	0.23	0.29	0.33	0.37
22.2	0.11	0.20	0.27	0.34	0.39	0.44
25.4	0.12	0.21	0.29	0.36	0.42	0.47
34.9	0.13	0.25	0.34	0.42	0.49	0.55

within a microirrigation dripline, which was simulated here with a clear PVC pipeline. In this laboratory experiment, silica sand and aluminum oxide sediments with sizes up to 500 µm, which are much larger than those in properly managed microirrigation systems, were used because this avoided turbidity issues from the more typical clay and silt particles, which are smaller than 50 µm. Although many of the laboratory results cannot be directly applied to field microirrigation driplines, the study results demonstrate the complex flow regimes that can occur within driplines during flushing. The results suggest that a flushing velocity of approximately 0.46 m s^{-1}, which is slightly greater than the theoretical deposition velocity for silica sand smaller than 250 µm, will remove approximately 99% of the sediments from a 25 mm internal diameter pipe in 15 min. At lesser velocities (i.e., 0.34 to 0.38 m s^{-1}), similar sediment removals can still be achieved, but longer flushing times are necessary. Under more realistic microirrigation conditions (i.e., soil particles smaller than 75 µm, a lower concentration of solids of less than 2%, and smaller driplines with diameters less than 25 mm), flushing velocities around 0.3 m s^{-1} would appear to be adequate. The combined use of the Durand and Condolios (1952) and the Schiller and Herbich (1991) equations to calculate the deposition velocity is recommended for helping to assess the potential for insufficient flushing capability in new microirrigation system designs. Increasing the duration of flushing would be an inexpensive means of increasing the adequacy of flushing without requiring a greater flushing velocity, which increases system cost. This study did not evaluate the complexities of the flow regime that might occur when emitters are present and discharging water or when emitters are affecting the turbulence within the dripline (i.e., internal welded-on emitters protruding into the flow stream), so further research would be useful to investigate those interactions.

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