

7-2008

Applying Polyacrylamide (PAM) to Reduce Seepage Loss of Water Through Unlined Canals

Jianting Zhu
Desert Research Institute

Michael H. Young
Desert Research Institute

Follow this and additional works at: http://opensiuc.lib.siu.edu/ucowrconfs_2008
Abstracts of presentations given in Session 5 of the UCOWR conference.

Recommended Citation

Zhu, Jianting and Young, Michael H., "Applying Polyacrylamide (PAM) to Reduce Seepage Loss of Water Through Unlined Canals" (2008). 2008. Paper 24.
http://opensiuc.lib.siu.edu/ucowrconfs_2008/24

This Article is brought to you for free and open access by the Conference Proceedings at OpenSIUC. It has been accepted for inclusion in 2008 by an authorized administrator of OpenSIUC. For more information, please contact opensiuc@lib.siu.edu.

APPLYING POLYACRYLAMIDE (PAM) TO REDUCE SEEPAGE LOSS OF WATER THROUGH UNLINED CANALS

Jianting Zhu and Michael H. Young

Desert Research Institute, Nevada System of Higher Education, Las Vegas, NV.

Summary

High molecular weight, linear, anionic polyacrylamide (PAM) is under investigation as a means of sealing unlined water delivery canals, thus potentially increasing the amount of water for downstream users. This study uses a two-layer conceptual model to explore the mechanism of reducing water loss from seepage. The ratio of PAM-treated versus untreated soil saturated hydraulic conductivity values is first calculated based on laboratory measured results. The seepage ratio of water infiltration through the unlined canal bottom before versus after PAM treatment is then derived using the two-layer conceptualization. Results illustrate that the PAM applications are only effective for sand- or coarse-textured bottom canals, when the reduction of hydraulic conductivity due to PAM treatment is most significant.

Introduction

The U.S. Geological Survey (USGS) (1990) has estimated that as much as 50 percent of water flowing through unlined water delivery canals could be lost from seepage through canal bottoms or sidewalls. High molecular weight, linear, anionic polyacrylamide (PAM) is under investigation as a means of sealing unlined water delivery canals to reduce seepage or infiltration losses. Using PAM as a means to reduce infiltration for water conservation is a relatively new, but important, application that only recently has been considered. One of the earlier known reports of this usage was by Valliant (1999), who showed in a scaled-down trough that PAM and sediment together could reduce seepage by 60%. Because of the ongoing drought in the western United States and the results of field studies, the U.S. Bureau of Reclamation (USBR) began a concerted effort to evaluate the use of PAM as a means of sealing unlined water delivery canals, and whether the benefits of PAM usage outweighed the potential environmental effects of this technology.

As part of the USBR-sponsored studies, Young et al. (2007) and Moran (2007) quantified the optimum PAM and suspended sediment concentrations (SSC) that most efficiently reduce saturated hydraulic conductivity (K_s) of soil columns in the laboratory. Their results show that PAM treatment reduces K_s from 40% to 98% in sandy-textured materials, depending on the SSC, but reductions were much less in a loamy sand soil (from 0 to 56%). Their results also show that the combination of PAM and SSC together reduces K_s of the entire soil column from 8 to 11 times more than adding PAM without suspended sediment. Given the differences between field and laboratory experimental conditions, the relatively new usage of PAM as a canal sealant, and the overall difficulty in controlling field conditions that affect PAM hydration and reactivity (i.e., turbidity levels, water temperature, etc.), there is a need to develop an overall better understanding of when and to what extent PAM could be an effective sealant.

In this study, we try to fill one of the knowledge gaps and develop a simple conceptual framework to explore the physical and hydraulic mechanisms of seepage reduction when unlined canals are treated with PAM. The objective of this study is to quantify potential water seepage reduction from forming thin, PAM-treated layers at the bottom of water delivery canals. The study incorporates K_s results from previous laboratory experiments, and applies them to field scenarios using a conceptual framework for vertical flow in layered systems for soils beneath the water delivery canals.

Methods and Materials

The ratio of effective saturated hydraulic conductivity after PAM treatment (K_{seff}) and that for the original intact soils (K_{s1}), or K_{seff}/K_{s1} , was measured using a one-dimensional saturated column in the laboratory (Young et al., 2007; Moran, 2007). The one-dimensional column experiments showed that, after PAM treatment, the soil column could be conceptualized as a system with distinct two layers. On top of the soil is a very thin layer of a mixture of PAM/sediment and other settling sediment, possessing a saturated hydraulic conductivity which is smaller than the original intact soil at the bottom of the column. This phenomenon was described as a thin-layer seal by Lentz and Freeborn (2007). Given that K_{seff} of such a two-layer system is equal to the harmonic mean of the hydraulic conductivities of respective layers (e.g., Freeze and Cherry, 1979), we can estimate the hydraulic conductivity of the PAM-coated layer, expressed as a ratio of hydraulic conductivities. Using the measured K_{seff}/K_{s1} values and an estimated (assumed) thickness of PAM-coated soil layer, d , we can calculate the ratio of hydraulic conductivity of the PAM-coated layer over that of the original intact soils, K_{s2}/K_{s1} , as follows,

$$\frac{K_{s2}}{K_{s1}} = \frac{\left(\frac{d}{h_{col} - d}\right) \frac{K_{seff}}{K_{s1}}}{\frac{d}{h_{col} - d} + 1 - \frac{K_{seff}}{K_{s1}}} \quad (1)$$

where K_{s2} is the saturated hydraulic conductivity of the uppermost PAM-coated soil layer, and h_{col} is the column height (or soil thickness) in the laboratory experiment (or field site).

We assume that flow in the water delivery canal reaches equilibrium after some time and remains stable (i.e., no change the canal water level and the level of groundwater table). This is typically the case after the winter snow melt has ended and as the canals are fully charged with water. We also assume that infiltration through side walls of the water delivery canal is small compared to the vertical infiltration. Using these two assumptions, the flow process can be considered as steady-state, one-dimensional vertical infiltration through two-layer soils with distinct and contrasting hydraulic properties, as shown in Figure 1.

For steady state conditions, Darcy's law gives

$$z - z_i = \int_{\psi_i}^{\psi} \frac{d\psi}{1 + (q/K)} \quad (2)$$

where z is the elevation from the ground-water table, increasing in the vertical upward direction, ψ is the capillary pressure head, $\psi = \psi_i$ at location z_i , q is the Darcian velocity (flux rate) and $K(\psi)$ the hydraulic conductivity function.

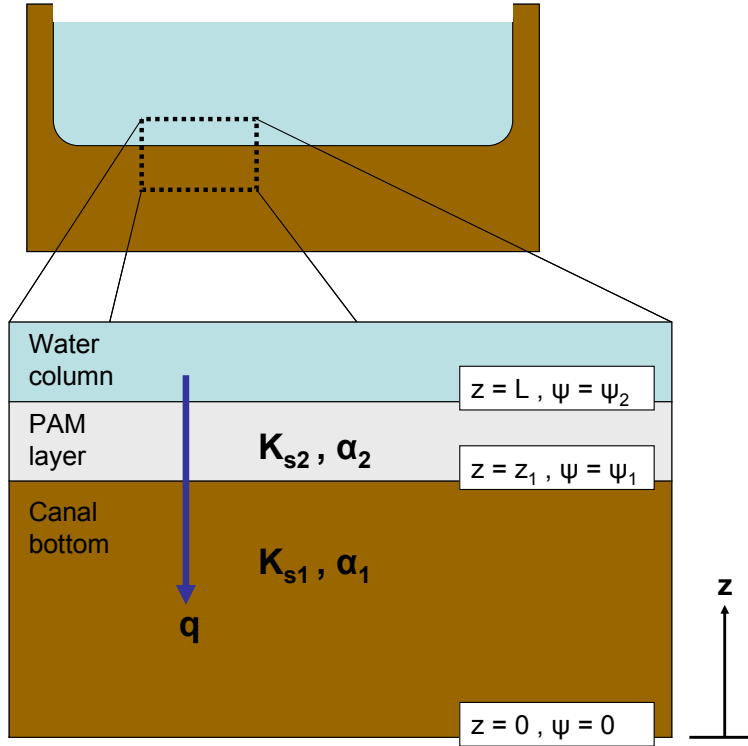


Figure 1: Schematic view of two-layer soils with distinct hydraulic properties underneath canal water.

The Gardner model (Gardner, 1958) for hydraulic conductivity function is used

$$K = K_s \exp(-\alpha\psi) \quad (3)$$

where α is a parameter that influences the decline in hydraulic conductivity with soil water potential (called pore-size distribution parameter in some literature). Other widely used hydraulic property functions should lead to a similar trend for the following analysis, although results may differ numerically.

For the Gardner hydraulic conductivity function (Eq. 3), we show that (see Figure 1 for symbol meaning)

$$z_{i+1} - z_i = \frac{1}{\alpha_{i+1}} \ln \frac{K_{s_{i+1}} e^{-\alpha_{i+1}\psi_i} + q}{K_{s_{i+1}} e^{-\alpha_{i+1}\psi_{i+1}} + q} \quad (4)$$

For two-layer system as conceptualized in this study, we can obtain

$$\left[e^{-\alpha_1 L} + \frac{p}{K_{s1}} (1 - e^{-\alpha_1 L}) \right]^\beta + \frac{p}{K_{s1}} \frac{1}{\delta} (e^{\beta \alpha_1 d} - 1) = e^{\beta \alpha_1 (d+h)} \quad (5)$$

where $\beta = \alpha_2 / \alpha_1$, $\delta = K_{s2} / K_{s1}$.

The infiltration rate p (i.e., seepage loss rate) can thus be solved iteratively from the above equation, which should be relatively easily solved for p/K_{s1} , because the two terms in the left hand side of Eq. 5 are both greater than 0 and increase monotonically versus p/K_{s1} . Then the ratio of the seepage rate for the two-layer soil system created from PAM treatment over the untreated single-layer soil system (designated in the subscript as *WOP*) can be defined as

$$r = \left(\frac{p}{K_{s1}} \right) \bigg/ \left(\frac{p}{K_{s1}} \right)_{WOP}$$

This ratio represents the fraction of water seepage through the unlined canal bottom after PAM treatment versus seepage loss without PAM treatment. Therefore this ratio can be considered as a measure of efficacy of PAM treatment for reducing water seepage loss. Hence, the smaller the r value, the more efficient are the PAM applications.

Results and Discussion

Three types of soil materials were used in laboratory experiments to investigate the effectiveness of reducing K_s of PAM and suspended sediment interactions (Young et al., 2007; Moran, 2007), (1) C33 sand collected from Grand Junction, Colorado area, (2) a #70 mesh sand obtained from a local home improvement store; and (3) loamy sand soil also collected from Grand Junction, Colorado area. The K_s values before PAM treatment (K_{s1}) and the effective hydraulic conductivity (K_{seff}) after PAM treatment were determined from laboratory experiments. The details of experiments are described in Young et al. (2007) and Moran (2007).

Figure 2 plots the actual K_s ratio, which was calculated from Eq. 1. While the distinct PAM-coated layer was clearly visible on the top of the soil column in some laboratory experiments, and the thickness of this layer was estimated in the order of less than 0.1 cm (Moran, 2007), and an accurate measurement of the layer thickness was difficult. Nonetheless, we use two thickness estimates (0.1 cm and 0.05 cm) for calculating the K_s for the PAM-coated layer. While the estimate of PAM-coated layer thickness d is rough, we will illustrate later the seepage loss ratio is not sensitive to d . Figure 2 shows the calculated results for cases where $d = 0.1$ cm and $d = 0.05$ cm. As expected, a smaller d value resulted in a smaller K_s for the PAM-coated layer, for the same measured effective hydraulic conductivity of the two-layer column, as indicated by the open symbol curves in Figure 2.

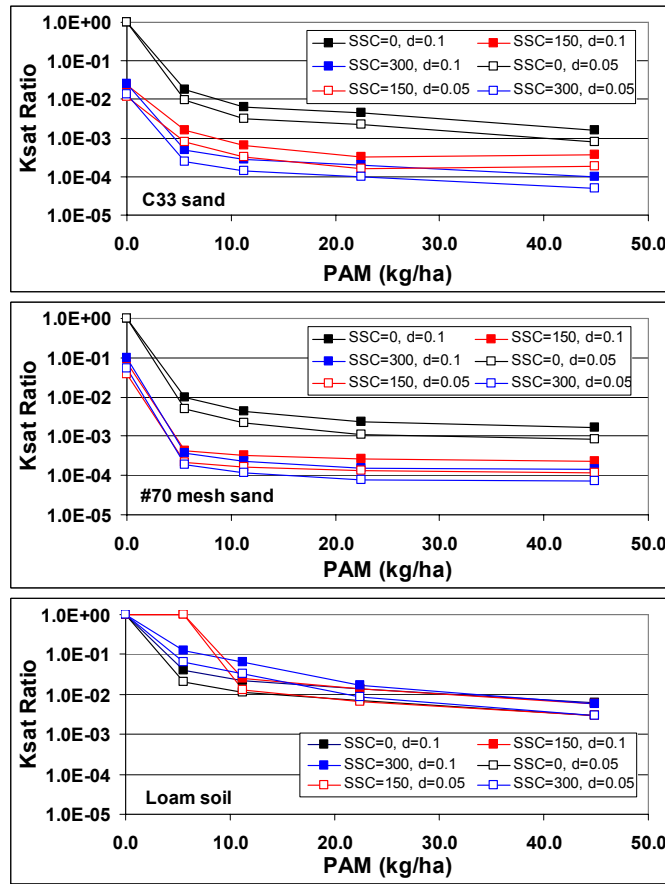


Figure 2: Saturated conductivity ratio of PAM-coated layer over original soil after PAM and SSC treatment, (a) C33 sand, (b) #70 mesh sand, and (c) loamy sand

Because estimates of α are not available, we use some typical values (Carsel and Parrish, 1988) for the soil types used in the experiments. Specifically, $\alpha = 0.145$ (1/cm) for C33 sand and $\alpha = 0.036$ (1/cm) for loamy sand soil. We use a value of $\alpha = 0.1$ (1/cm) for the #70 mesh sand, which is between sand and loamy sand groups but is closer to the sand group. Figure 3 shows the calculated results of seepage rate ratio as functions of PAM treatment level (expressed in kg/ha) for conditions when the water table depth from the canal bottom (L) = 400 cm, the canal water depth (h) = 50 cm, and PAM-treated soil layer thickness (d) = 0.1 cm. Because we have measured the K_{seff} for the column, including the PAM-treated top layer, the thickness of the top layer will dictate the K_s of the PAM-treated layer, as shown in Figure 2. If other PAM-treated layer thicknesses are used, the seepage ratio results will be very similar to the ratios shown in Figure 3 if other parameters values are the same (results not shown). The results indicate that the measured K_{seff} of the laboratory column is a good indication of seepage reduction from field treatment, even though the bottom intact layer in the field conditions might be mostly unsaturated. The results and conclusions reported for $d = 0.1$ cm should also hold for other assumed value for the PAM-treated layer thickness. Results in Figure 3 show that, in general, PAM and SSC treatments are most effective for sandy-textured materials, while treatment was

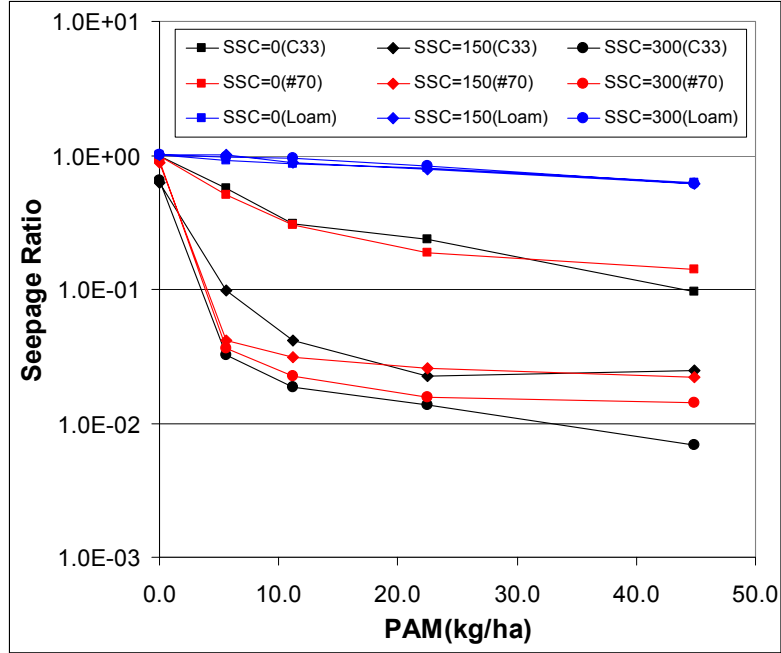


Figure 3: Seepage ratio, r , vs. PAM applications (expressed in kg/ha) when $\beta = 1$, $L = 400$ (cm), and $h = 50$ (cm), and $d = 0.1$ (cm) at various SSC levels.

not effective in reducing seepage loss for loamy sand soil. In general, PAM treatment increases the effectiveness of seepage reduction as it reduces the seepage ratio when its concentration (in kg/ha) is increased. Larger SSC also has the effect of reducing the seepage ratio. However, the efficiency of combining PAM and SSC is not linear. The seepage ratio decreases dramatically between 0 and 22.4 kg/ha, but the reduction efficiency diminishes when PAM concentration is increased to 44.8 (kg/ha), as seen by a stabilization of the seepage ratio. For the finer-textured loamy sand soil, the seepage reduction is minimal, while for C33 and #70 mesh sand, seepage was reduced to only about 1% of the original value. Therefore, PAM application and SSC treatment are most effective in reducing water seepage in coarse-textured water delivery canals.

As a final caveat, we note that results presented are the seepage ratio of treated over untreated native soils, not the actual seepage rate. Caution should be used when interpreting the results for different soil types. A smaller seepage ratio for sand as compared with loamy sand simply means the PAM application is more effective for sand than for loamy sand in terms of reducing seepage losses from the unlined canals. The results do not necessarily mean that overall seepage loss is smaller for the sand than for the loamy sand.

Concluding Remarks

This study developed a simple model of estimating seepage reduction in unlined water delivery canals as a result of PAM and SSC treatments. The PAM applications are most effective for sand- or coarse-textured bottom canals and least effective (ineffective) for finer-grained (loamy sand) bottom canals. Measured effective saturated hydraulic conductivity of the laboratory column is a good indication of seepage reduction from field treatment.

Acknowledgement: The funding support by U.S. Bureau of Reclamation, under cooperative agreement #05-FC-81-1165, is greatly appreciated. Del Smith is the Program Manager. We also thank Ernesto Moran for providing laboratory testing results of saturated hydraulic conductivities and helpful discussion.

References

- Carsel, R. F., and R. S. Parish. 1988. Developing joint probability distributions of soil water retention characteristics. *Water Resources Research* 24(5):755-769.
- Freeze, R. A., and J. A. Cherry. 1979. Groundwater. Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 604 p.
- Gardner, W. F. 1958. Some steady-state solutions of unsaturated moisture flow equation with application to evaporation from a water table. *Soil Science* 85(2):228-232.
- Lentz, R.D. and L. L. Freeborn. 2007. Sediment and polyacrylamide effects on seepage from channeled flows. *Soil Science* 172(10):770-789.
- Moran, E. A. 2007. Laboratory studies to examine the impacts of polyacrylamide (PAM) on soil hydraulic conductivity. Master's Thesis, Department of Geological Sciences, University of Nevada Las Vegas.
- U.S. Geological Survey (USGS). 1990. National Water Summary 1987 – Hydrologic Events and Water Supply and Use. U.S. Geological Survey Water Supply Paper 2350. U.S. Government Printing Office, Denver Colorado.
- Valliant, J. 1999. PAM: A cost effective tool for improving irrigation and protecting soil and water resources. Colo. State Univ., Soil and Crop Sciences, Drought Newsletter 1999. www.colostate.edu/Depts/SoilCrop/extension/Newsletters/1999/gujune99.htm
- Young, M. H., J. Woodrow, D.P. Moser, J. Zhu, L. Chen, R.B. Susfalk, G.C. Miller, S.K. Labahn, E.A. Moran, T. Arrowood. 2007. Results of Laboratory Experiments in Support of PAM-related Research. Edited by M.H. Young. Desert Research Institute Publication, No. 41237.

Author contact information:

Jianting Zhu
Desert Research Institute
755 E Flamingo Road
Las Vegas, NV 89119
(702) 862-5416
Jianting.Zhu@dri.edu

Michael H. Young
Desert Research Institute
755 E Flamingo Road
Las Vegas, NV 89119
(702) 862-5489
Michael.Young@dri.edu