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Polyacrylamide Removes Microorganisms and Nutrients from Surface Water

J.A. Entry[1], R.E. Sojka[1], S.A. Verwey[1] and C.W. Ross[2]

[1]USDA Agricultural Research Service, Northwest Irrigation and Soils Research Laboratory, Kimberly, Idaho
[2]Landcare Research, Massey University, Palmerson North, New Zealand

Abstract

Waste streams associated with a variety of agricultural runoff sources are major contributors of nutrients, pesticides and enteric microorganisms to surface and ground waters. Water soluble anionic polyacrylamide (PAM) was found to be a highly effective erosion-preventing and infiltration-enhancing polymer, when applied at rates of 1 to 10 gm^{-3} in furrow irrigation water. Water flowing from PAM treated irrigation furrows show large reductions in sediment, nutrients and pesticides. Recently PAM, PAM+CaO and PAM+$Al(SO_4)_3$ mixtures have been shown to filter bacteria, fungi and nutrients from animal wastewater. Low concentrations of PAM (175-350 grams PAM ha^{-1} as PAM or as PAM+CaO and PAM+$Al(SO_4)_3$ mixture) applied to the soil surface, resulted in dramatic decreases (10 fold) of total and fecal coliform bacteria and fecal streptococci in cattle, fish, and swine wastewater leachate and surface runoff. PAM treatment also filtered significant amounts of NH_4, PO_4 and total P in cattle and swine wastewater. This points to the potential of developing PAM as a water quality protection measure in combination with large-scale animal feeding operations. Potential benefits of PAM treatment of animal facility waste streams include: 1) low cost 2) easy and quick application 3) suitability for use with other pollution reduction techniques. Research on the efficacy of PAM for removal of protozoan parasites and viruses and more thorough assessment of PAM degradation in different soils is still needed to completely evaluate PAM treatment as an effective waste water treatment. We will present analysis and feasibility of using PAM, PAM+$Al(SO_4)_3$, and PAM+CaO application for specific applications. Our results demonstrate their efficacy in reducing sediment, nutrients and microorganisms from animal production facility effluents.

Introduction

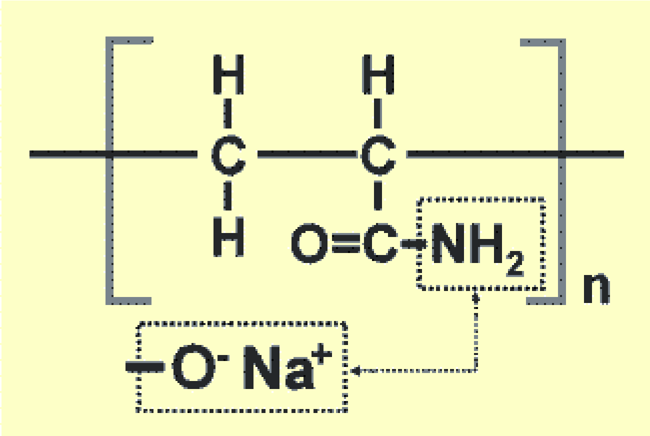
Agriculture is the most wide spread source of water pollution in the United States (USEPA, 1998). For decades, most surface water quality protection from agriculture has focused on soil erosion and related non-point sources that contribute to surface water contamination (Figure 1). In the last decade, there has been a shift in animal rearing towards large scale confined animal feeding operations (CAFOs). CAFOs are the primary source of agricultural pollution and pose a number of risks to water quality and public health due to the large amount of manure generated. Sources of water pollution from CAFOs include direct discharges, open feedlots, treatment and storage lagoons, manure stockpiles and land application of manure to fields. Animal waste from CAFOs are a major source of enteric microorganisms and nutrients such as nitrogen (N) and phosphorus (P) to our nation's water systems.

Liquid-waste discharge onto soil may initiate solute and microbe movement into the soil following natural ground water drainage patterns and contaminating adjoining surface water. These same bodies of water are often sources of drinking water and/or used for recreational activities. Human contact with recreational waters containing intestinal pathogens is an effective method of disease transmission. Therefore, it is critical to employ appropriate treatment strategies in order to maintain the quality of our lakes and streams and keep them free of intestinal pathogens and excess nutrients.

Figure 1. Photo of water flowing in irrigation furrows without polyacrylamide treatment of the water (left) and after polyacrylamide treatment of the water (right).
(click on image to enlarge)

Polyacrylamide

Polyacrylamide is a generic chemistry term, referring to a broad class of compounds. There are hundreds of specific PAM formulations that vary in polymer chain length and number and kinds of functional group substitutions. In some chain segments PAM amide functional groups are substituted with groups containing sodium ions or protons. They freely dissociate in water, providing negative charge sites (Figure 2). In PAM formulations used for erosion control, typically one in five chain segments provide a charged site in this manner. These formulations are water soluble (linear, not gel-forming, not cross-linked, not super water-absorbent) anionic polymers with typical molecular weights of 12 to 15 Mg $mole^{-1}$ (more than 150,000 monomer units per molecule). They are commercially available as industrial flocculent polymers that accelerate separation of solids from aqueous suspensions in sewage sludge dewatering, mining, paper manufacture, clarification of refined sugar and fruit juices and as a thickening agent in animal feed preparations. Large anionic PAM molecules are used for



erosion control mainly for environmental and safety considerations. Commercial, anionic, moderate molecular-weight PAM products for erosion control are usually of two types. The most commonly used PAM products are fine granular forms. The second most common product formulations are concentrated liquid emulsions of PAM and mineral spirits. The latter category includes emulsions that contain a surfactant to help disperse the PAM when mixed with water. Emulsions are more commonly used with sprinkler PAM application than in furrow irrigation. Both granular materials and emulsified concentrates require substantial turbulence or agitation and high flow rate at the point of addition to water in order to dissolve PAM.

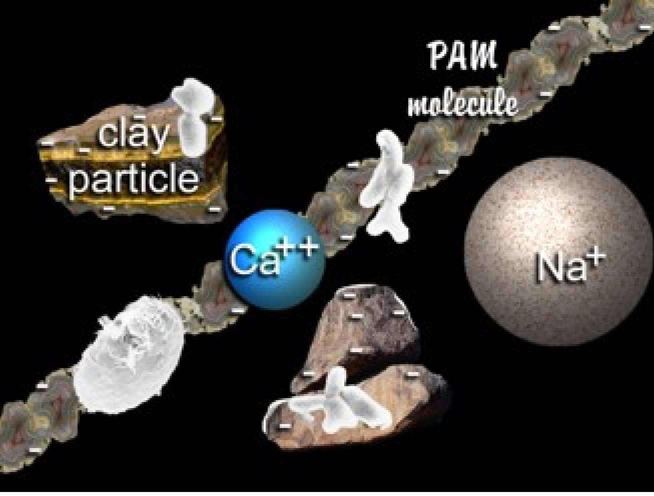
Figure 2. Diagram of a repeating unit in a polyacrylamide molecule showing potential substitution of a sodium formate functional unit to allow aqueous dissociation of Na^+ to provide a net negative charge site on the polymer macro molecule.
(click on diagram to enlarge)

Environmental and Safety Concerns

Environmental and safety considerations of anionic PAMs have been reviewed (Barvenik, 1994). The most significant environmental effect of PAM use is its erosion reduction, protecting surface waters from sediment and other contaminants washed from eroding fields. PAM greatly reduces nutrients, pesticides, and biological oxygen demand (BOD) of irrigation return flows. In Australian tests of PAM, sediment, nutrient, and pesticide reductions exceeded levels achieved by traditional conservation farming methods. In soil, PAM degrades at rates of at least 10% per year as a result of physical, chemical, biological and photochemical processes and reactions. Because PAM is highly susceptible to UV degradation, its breakdown rate when applied at the soil surface for erosion control may be faster than the above-cited 10% per year reported rate, which was for biological degradation of PAM mixed into a large soil volume.

Used at prescribed rates, anionic PAMs are environmentally safe. Cationic and neutral PAMs have toxicities warranting caution or preclusion from sensitive environmental uses. The US Department of Agriculture, National Resource Conservation Service (NRCS) specifies anionic PAMs for controlling irrigation-induced erosion. Negative impacts have not been documented for aquatic macrofauna, edaphic microorganisms, or crop species for the anionic PAMs used for erosion control when applied at recommended concentrations and rates (Kay-Shoemake 1998a,b).

Polyacrylamide Degradation in Soil and Water

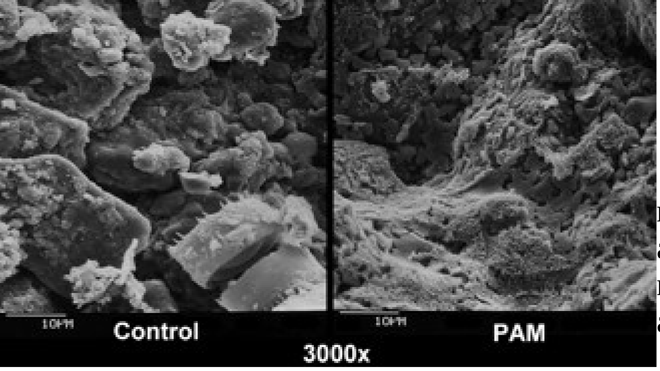


PAM degradation rates in soil are estimated to be approximately 10% $year^{-1}$ (Barvenik, 1994). Degradation of the acrylamide monomer (AMD) is fairly rapid. AMD was completely degraded within 5 days after applying 500 mg PAM kg^{-1} garden soil (Shanker et al., 1990). Lande et al. (1979) applied 25 mg PAM kg^{-1} soil and reported that half life of an AMD in agricultural soils was 18-45 hr. There have been mixed, and sometimes conflicting, reports regarding the effects of PAM application on bacterial biomass levels in soils and waters. Kay-Shoemake et al. (1998) found higher culturable heterotrophic bacteria in PAM-treated soils planted to potatoes, but not in those planted to beans. These observations, along with other studies showing either increases or decreases in bacterial numbers for PAM-treated soils, indicate that these effects are likely site-specific and may interact with other important variables, such as nutrient levels, crop cover type or herbicide regimes.

Figure 3. Conceptual diagram of a polyacrylamide molecule adhering to soil particles, a calcium ion with relatively small hydrated radius, a sodium ion with a relatively large hydrated radius and microorganisms. The diagram is not to scale.
(click on image to enlarge)

Polyacrylamide Use for Removal of Enteric Bacteria and Nutrients from Wastewater

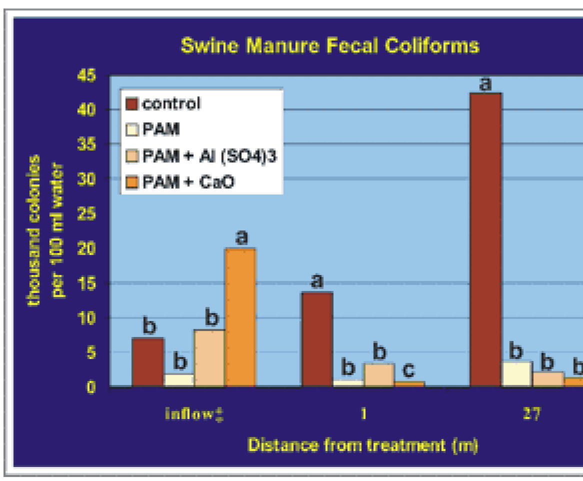
Sojka and Entry (2000) found that after water traveled 1 meter at 7.5 and 15.5 liter min^{-1}, PAM-treatment reduced algae, total bacterial and microbial biomass and total fungal biomass relative to the control treatment. After water traveled 40 meters at 7.5, 15.5, and 22.5 liter min^{-1}, PAM-treatment reduced algae, the numbers of active and total bacteria, active and total fungal length, total bacterial biomass, total fungal and microbial biomass relative to the control treatment. In a study to determine the efficacy of PAM to remove enteric bacteria and nutrients from animal wastewater, Entry and Sojka (2000) found that PAM+$Al(SO_4)_3$, and PAM+CaO mixtures reduced populations of total and fecal coliform bacteria and fecal streptococci in cattle, fish, and swine wastewater leachate and surface runoff by approximately one hundred to one thousand fold compared to no treatment. PAM reduced populations of total coliform and fecal coliform bacteria in swine manure leachate from columns containing four different soil types ranging from sand to clay by at least ten fold compared to soil columns without PAM (Entry et al., 2002). The PAM mixtures should not be expected to sterilize water, but they should be able to substantially reduce the numbers of pathogenic bacteria in runoff prior to entering public water systems. PAM+$Al(SO_4)_3$, and PAM+CaO compounds also removed significant amounts of NH_4^+, PO_4^{-3} and total P in cattle and swine wastewater leachate and surface runoff (Entry and Sojka, 2001). These compounds should be able to reduce these pollutants from wastewater flowing from animal confinement areas. If nutrient concentrations in wastewater are low, there is less chance that they will contact binding sites on the PAM



molecule or Al^{+3} and Ca^{+2}. Therefore PAM+$Al(SO_4)_3$, and PAM+CaO may be unable to further remove nutrients from wastewater when nutrient concentrations are already extremely low.

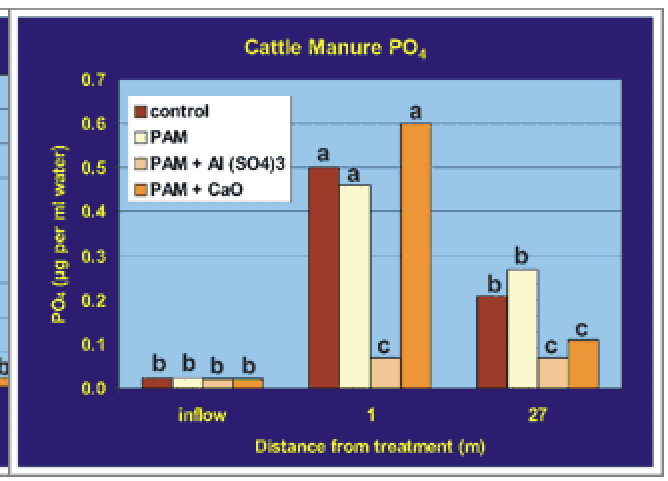
Sojka and Entry (2000) showed that bacteria were effectively removed from water flowing in furrows at rates from 7.5 to 22.5 liters min^{-1}. As flow rates increased, PAM removed a smaller percentage of bacteria from water. PAM+$Al(SO_4)_3$ or PAM+CaO patches are increasingly effective at lower flow rates. When PAM molecules are dissolved in water and adhere to microorganisms or nutrients they may stay dissolved until the molecule adheres to an object that is heavy enough to settle out of the flow. This would explain why PAM, PAM+$Al(SO_4)_3$ and PAM+CaO in faster flowing water is not as effective as the same treatments in slower flowing water. The effectiveness of these compounds may be increased if sand or silt size particles are present in the water flow. Various PAM formulations are routinely used in municipal water treatment facilities for sewage sludge dewatering and for finish treatment of potable drinking water. The ability of PAM to flocculate microorganisms and remove them from water treatment facilities has been understood for some time (Barvenik, 1994).

Figure 4. Scanning electron photographs of soil without polyacrylamide (PAM) added to the irrigation water (left) and after PAM treatment of the water (right). Note the matting of the PAM residue, which is thought to increase soil structural stability and increase force needed to induce the particle detachment that causes erosion.
(click on image to enlarge)



Graph 1. Efficacy of PAM, PAM + Al $(SO_4)_3$ and PAM + CaO to remove **fecal coliform bacteria**; water flowing at 8.6 L min^{-1} over 8.6 L of hog manure.†

† In each column, values followed by the same letter are not significantly different



Graph 2. Efficacy of PAM, PAM + Al $(SO_4)_3$ and PAM + CaO to filter **PO_4** in cattle wastewater flowing at 8.6 L min^{-1} over 8.6 L of manure.†

† In each column, values followed by the same letter are not significantly different

as determined by the least square means test (P<0.05), n=27. Inflow water was sampled prior to flowing over animal waste. (click on graph to enlarge)

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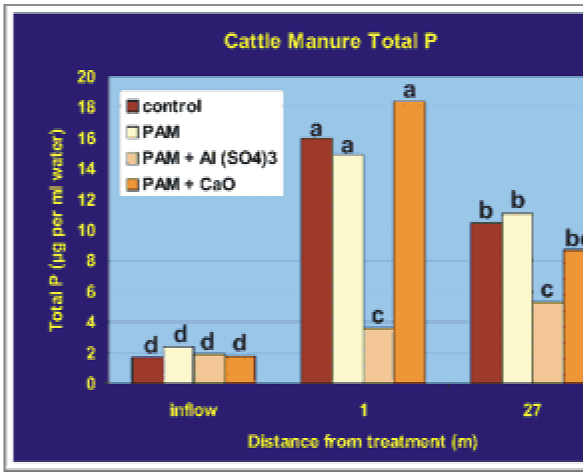
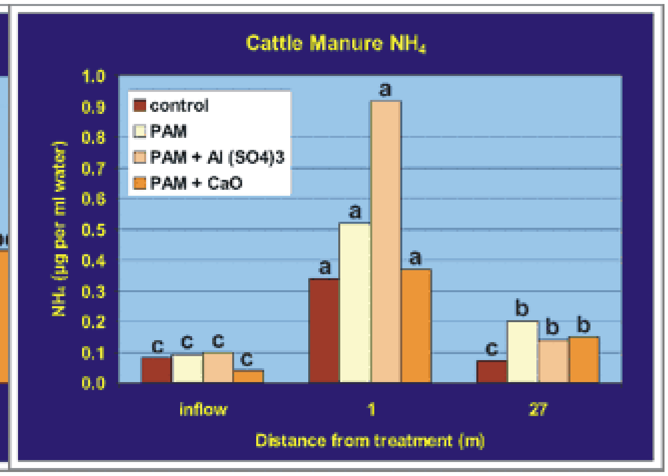


Graph 3. Efficacy of PAM, PAM + Al $(SO_4)_3$ and PAM + CaO to filter **Total P** in cattle wastewater flowing at 8.6 L min^{-1} over 8.6 L of manure.†

† In each column, values followed by the same letter are not significantly different as determined by the least square means test (P<0.05), n=27. (click on graph to enlarge)

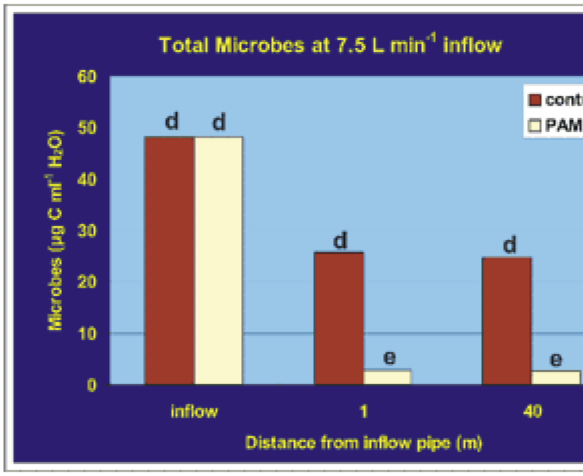


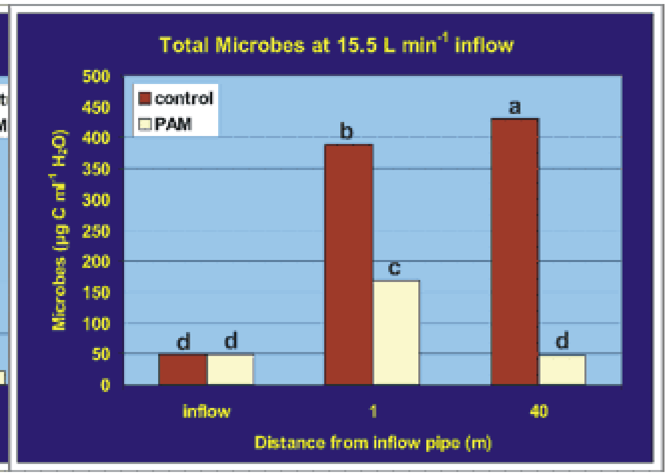
Graph 4. Efficacy of PAM, PAM + Al $(SO_4)_3$ and PAM + CaO to filter $\mathbf{NH_4}$ in cattle wastewater flowing at 8.6 L min^{-1} over 8.6 L of manure.†

† In each column, values followed by the same letter are not significantly different as determined by the least square means test (P<0.05), n=27. (click on graph to enlarge)

Graph 5. Efficacy of PAM to filter **Total Microbes** in wastewater flowing at **7.5** L min^{-1} over 8.6 L of manure.†

Graph 6. Efficacy of PAM to filter **Total Microbes** in wastewater flowing at **15.5** L min^{-1} over 8.6 L of manure.†





† In each column, values followed by the same letter are not significantly different as determined by the least square means test (P<0.05), n=27. (click on graph to enlarge)

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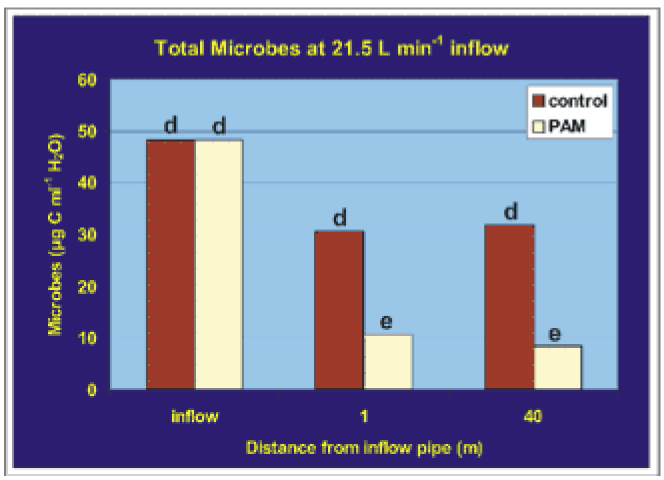

Graph 7. Efficacy of PAM to filter **Total Microbes** in wastewater flowing at **21.5** L min^{-1} over 8.6 L of manure.†

† In each column, values followed by the same letter are not significantly different as determined by the least square means test (P<0.05), n=27. (click on graph to enlarge)

Future Research

Future research may be directed toward efficacy of PAM-related compounds to remove specific bacterial species from waste water. We have not found reports investigating the ability of PAM compounds to remove specific species of disease-causing bacteria or fungi. These tests may require the release of specific bacteria such as *Escherichia coli* O157:H7 or *Salmonella typhi* in controlled water environments. We have not found reports investigating the efficacy of PAM, PAM+$Al(SO_4)_3$, and PAM+CaO to remove protozoan parasites such as *Giardia lamblia*, *Cryptosporidum sp.* including *C. parvum,* or *Entamobea histoltica* in a free living and cyst form. Since PAM compounds remove larger organisms like fungi and algae from waste water, we speculate that they might remove protozoans with similar efficiency.

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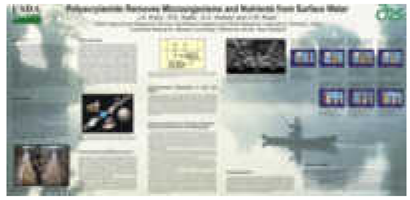

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