PAM & PAM Alternatives Workshop

Session Two: Overview of PAM Research Conducted by the Agricultural Research Service

USDA-ARS Perspective on PAM

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What is polyacrylamide (PAM)?

Polyacrylamide (PAM) is a synthetic organic polymer derived from petroleum. It is an industrial flocculent used worldwide in several industries. For example, one international manufacturer of PAM markets 31 percent of its PAM product to the municipal potable and waste water treatment industry, 18 percent to paper production, 17 percent to industrial water treatment, 13 percent to oil production (enhanced oil recovery), 9 percent to mining, and the remaining 8 percent to agriculture, animal feed, and cosmetic industries. Since agriculture is a relatively small market, the polymer manufacturers commit only limited resources toward developing or improving agricultural polymer products. This is why the research conducted by the U.S. Department of Agriculture, Agricultural Research Service (USDA-ARS) and others toward developing PAM technologies has been crucial to growing its potential and useful application in irrigated agriculture. The PAM used in furrow irrigation erosion control is a water soluble, anionic, high molecular weight, 12 to 15 Mg mol^{-1} (i.e., >150,000 repeating units) polymer with moderate charge density (~18 % of the repeating units are negatively charged). This PAM is also referred to as water soluble PAM (WSPAM) or linear anionic PAM (LAPAM). This long, single-chain polymer can be dissolved in water, where it forms a hydrated random coil structure. The size of the PAM hydrated coil increases with increasing molecular weight and charge density, and decreasing salt concentration in the water. Loops and tails of the hydrated polymer extend out into the water. Negatively charged sites on the polymer form electrostatic bonds with negatively charged sites on soil particles through intervening positively charged cations, Ca^{2+}, Mg^{2+}, and others. Thus, the polymer can bind soil particles together via a so-called cationic bridge, which is one of the main mechanisms by which PAM interacts with soil.

Polyacrylamide can be obtained in several forms. The granular form consists of white table-sugar-sized crystals and includes between 75 and 97 percent active ingredient (AI), 3 to 10 percent water, and a maximum 0.05 percent acrylamide monomer content (for food-grade products recommended for agricultural use). Granular PAM may also include 0 to 10 percent dissolution aids (e.g., urea) and/or enhancers (Ca^{2*}, Mg^{2+}). Aqueous PAM solutions may be available in some locations, but viscosity limits their AI content to a maximum of about 3 percent (w/w). Polyacrylamide can also be obtained as an emulsion. Emulsions contain 25 to 50 percent AI (w/w), 5 to 30 percent water, 30 percent mineral oil, and 5 to 10 percent surfactants, emulsifiers and inverters. The acrylamide monomer content in PAM emulsions potentially can be much less than 0.05 percent.

Users should be aware that anionic PAM can be obtained in a cross-linked form, which, unlike the linear molecule, is not soluble in water. The linear PAM molecules are bound to one another via chemical bonds, creating a massive molecule that is able to absorb 60 to 600 times its weight in water, depending on water quality.

PAM Research at Kimberly

PAM research at the USDA-ARS Northwest Irrigation and Soils Research Laboratory in Kimberly, ID, began in 1991 as a cooperative effort with Dr. Isaac Shainberg, then a visiting scientist at the USDA-ARS Soil Erosion Laboratory, West Lafayette, IN. He had observed that water-soluble PAM reduced sediment loss in a laboratory rill study and asked interested researchers at Kimberly if PAM might have an application in irrigation furrows. We set up some field experiments to test the concept and the study produced dramatically successful results. At that point, PAM research at Kimberly accelerated (Appendix A). One research thrust refined application strategies for erosion control. Several studies examined application strategies for reducing sediment and/or increasing infiltration: 1) the influence of application technique, timing, and PAM concentration was determined, and 2) the effects of PAM charge type, charge density, and molecular weight were studied. One experiment examined the interactions between PAM application and the presence of straw residue in furrows. Two PAM application methods were validated in above studies. One consistently successful application amends inflow irrigation water with 10 mg L^{-1} PAM only during furrow advance, completing the irrigation with untreated water. The second, commonly called the patch method, spreads 15 to 30 g PAM in the furrow at the inflow-end. It produces a continuous PAM application with 2 to 7 mg L^{-1} PAM dissolved in the furrow stream early in the irrigation and 0.2 to 2 mg L^{-1} PAM at later times. Still other research developed PAM applications for sprinkler irrigation.

A second research thrust examined PAM application effects on water quality. Experiments showed how PAM influences furrow stream and tailwater phosphorus and nitrate concentrations, chemical oxygen demand, and water temperature. Polyacrylamide effects on microorganism and weed seed concentrations in irrigation runoff were also investigated. Other studies were concerned with the effects of PAM treatment on percolation water and leaching of phosphorus, nitrate, ammonia, dissolved organic carbon, and some herbicides through soil profiles.

A third thrust delved into PAM interactions with soil microorganisms. Experiments showed how PAM affects microorganism populations in treated soil and how microorganisms can utilize PAM as a substrate.

A fourth research thrust focused on PAM effects on surface soil structure under sprinkler irrigation. Experiments were conducted to explore PAM's potential for reducing soil crusting and improving seedling emergence, particularly for small seeded crops such as sugarbeet.

A fifth research thrust sought to ascertain the fate of PAM that was applied to furrow irrigation water. This effort included developing a method for analyzing dissolved PAM concentrations in irrigation water. A subsequent mass-balance study tracked dissolved PAM loads in furrow and tailwater streams.

A sixth research thrust focused on the fate of the residual acrylamide monomer (AMD) present in the applied PAM product. The studies determined whether AMD was incorporated into harvested crop tissues, and if AMD was prone to leach below the crop root zone (see later discussion).

PAM: A Tool for Irrigated Agriculture

As a result of the extensive research conducted at the laboratory, Kimberly researchers concluded that PAM was an effective tool for irrigated agriculture. Research has conclusively shown that PAM applied in irrigated furrows:

1. Reduces soil loss 94 percent (80 to 99 percent)
2. Increases infiltration 15 percent (0 to 57 percent)
3. Increases lateral-wetting 25 percent
4. Decreases P- and chemical oxygen demand (COD)-losses approximately 75 percent
5. Reduces weed seed transport 81 percent
6. Reduces microbe transport 61 to 68 percent

Environmental Aspects

Research reported in the literature and conducted at the Kimberly laboratory indicates that, at concentrations used in furrow applications, PAM is nontoxic, degrades slowly in the soil to form H_2O and CO_2, and has variable effects on soil microorganisms, producing mainly proportional adjustments in individual populations relative to others. The concentration of PAM dissolved in furrow irrigation streams declines with travel downstream because PAM molecules adsorb to sediment and settle out. Since AMD occurs in small amounts in PAM products, it also is present in treated furrow streams. With respect to residual AMD present at concentrations less than 0.05 percent in PAM products, Kimberly research and that of others has documented the following: at recommended PAM product application rates, AMD in furrow irrigation streams should not exceed approximately 5 $\mu g\ L^{-1}$. While AMD is a neurotoxicant and suspected carcinogen in terrestrial mammals, it has low toxicity to aquatic organisms, degrades rapidly in soil and water streams, does not appear to accumulate in crop tissue, and does not leach beyond the root zone in medium-textured soils.

Many years of laboratory and field studies have resulted in a thorough documentation of the benefits and effectiveness of PAM for erosion control and infiltration management in irrigated agriculture. These results also provide strong evidence that PAM applied at recommended dosages in field irrigations has minimal negative environmental consequences. Polyacrylamide is one of several important tools available to farmers for reducing erosion and improving runoff water irrigation quality and should continue to be considered as part of a thoughtful management plan.

Appendix A: Contributors to Original PAM Research at the ARS Kimberly Laboratory

1991-1992:
Carter, D.L. (Ret.)
Lentz, R.D.
Sojka, R.E. (Ret.)

1993-1994:
Lentz, R.D.
Sojka, R.E. (Ret.)
Trout, T.J.

1995-1996:
Kincaid, D.C. (Ret.)
Lehrsch, G.A.
Lentz, R.D.
Sojka, R.E. (Ret)
Trout, T.J.

1997-1998:
Aase, J.K. (Ret.)
Bjorneberg, D.L.
Kincaid, D.C. (Ret.)
Lehrsch, G.A.
Lentz, R.D.
Robbins, C.W. (Ret.)
Sojka, R.E. (Ret)
Trout, T.J.
Westermann, D.T. (Ret.)

1999-2003:
Aase, J.K. (Ret.)
Bjorneberg, D.L.
Entry, J.A.
Kincaid, D.C. (Ret.)
Koehn, A.C.
Lentz, R.D.
Sojka, R.E. (Ret)
Westermann, D.T. (Ret.)

2004-2008:
Koehn, A.C.
Lentz, R.D.
Sojka, R.E. (Ret.)

Dr. Rodrick (Rick) D. Lentz is a soil scientist at the USDA-ARS Northwest Irrigation and Soils Research Laboratory in Kimberly, ID, where he has worked since 1991. He holds a B.S. degree in Biology from Portland State University; an M.S. in Soil Science from Oregon State University; and a Ph.D. in Soil Science from the University of Minnesota. During the last 16 years, his research has developed and evaluated various polyacrylamide applications for irrigated agriculture. His current research goals include 1) improving water quality of surface water and groundwater under irrigated agriculture; 2) conserving water resources by developing management practices to increase water application uniformity and reduce irrigation associated seepage losses; 3) enhancing our soil resources; and 4) increasing our ability to understand, describe, and predict irrigation furrow processes. Email: rick.lentz@ars.usda.gov; phone: 208-423-6531.