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Water quality in drip/trickle irrigation: A review

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Summary. The intensive treatment of irrigation water required for the proper operation of drip irrigation systems is presently an accepted practice. To control emitter clogging, we need to know the basic causes of clogging. The major clogging factors have been identified and control measures developed to prevent emitter malfunction. All emitter clogging problems, however, have not been solved primarily because of cost. The main approach to control clogging is proper water treatment. The type of treatment is based on the quality of the irrigation water, which can be classified in terms of its physical, chemical and biological composition. The causes of emitter clogging and possible water treatment and preventive measures to maintain reliable operation are reviewed.

Water quality and emitter clogging

Drip irrigation in the mid-1960's through mid-1970's was considered an emerging technology with its application limited only to high-priced, specialty crops. Today it is used on a wide variety of crops, even those that were initially considered unprofitable for management under drip irrigation.

Through careful nurturing, drip irrigation has grown into a stable and economically significant part of the farming community which has also had great impact on the irrigation and associated industries. In its infancy some difficult and seemingly unsolvable problems were encountered in operating drip/trickle systems particularly those related to the clogging of emitters. Also during this period, numerous inventors and entrepreneurs sold various types of "non-clogging" or "self-cleaning" emitters which were promised to solve the most serious problem of emitter plugging, but unfortunately did not adequately do so. The clogging problem, if not properly solved, would have resulted in the complete rejection or severe restriction of a promising, efficient method of irrigation and water conservation.

Work on improving drip system operations went along two different directions, independent, but closely in touch with one another. One group concentrated on improving the hydraulic operation of the emitters; the other focused on studying the clogging process and from such knowledge developing procedures for alleviating the clogging problem. The main conclusion drawn from the latter type of studies is that clogging is closely related to the quality of water used in the drip system, e.g. Bucks et al. (1977), Ford and Tucker (1975), Gilbert et al. (1981), McElhoe and Hilton (1974), Nakayama et al. (1977), Pelleg et al. (1974). Research continues to be reported on irrigation water quality, treatment, and uniformity of application (Hill et al. 1989; Kinoshita and Bui 1988; Padmakumari and Sivanappan 1985). Water diverted from other traditional irrigation usage is presently the major source for drip irrigation, but this situation is beginning to change toward use of wastewater from cities and industries. These types of water have different water quality, and consequently, different clogging parameters are involved so that different water treatment procedures must be used (Adin 1987; Adin and Elimelech 1989; Chandrakanth et al. 1988; Gamble 1986).

Causes of emitter clogging

For surface-placed drip systems, inspection of the flow behavior can readily determine when an emitter is operating properly. However, external examination alone cannot give an accurate evaluation of the cause or causes of emitter clogging. Most clogging starts inside the emitter and it may start very slowly and progress slowly or occur almost overnight. Partial clogging is just as bad as a complete clogging because they both reduce application uniformity and alter the hydraulics of the entire system. To determine the exact nature of the clogging process, careful physical, chemical, and biological examination of the emitters and supply lines must be made. In addition, the

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Table 1. Physical, chemical and biological factors involved in emitter clogging (Bucks et al. 1979)

Physical	Chemical	Biological
Inorganic materials	Alkaline earths	Algae
Sand (50–250 μm)	heavy metal	
Silt (2–50 μm)	cations	Bacteria
Clay (<2 μm)	calcium	filament
	magnesium	slime
	iron	
Organic materials	manganese	Microbial
	Anions	Activities
Aquatic plants	carbonate	iron
phytoplankton	hydroxide	manganese
algae	silicate	sulfur
	sulfide	
Aquatic animals		
zooplankton	Fertilizer sources	
snail	aqueous ammonia	
	iron	
Bacteria (0.4–2 μm)	copper	
	zinc	
Plastic cutting	manganese	
	phosphorus	
Lubricant residue		

composition of the water used in the system must be determined. Because of the variety of factors involved, a multidisiplinary approach must be taken. To focus further on the multiple causes of emitter clogging, a table was developed, which incorporates all the information available at that time on the factors contributing to clogging (Table 1).

The residues for a large number of emitters and tubing were examined chemically and microscopically to ascertain the components of the clogging material. Information on the compositions for various water sources and the related clogging problems at the respective sites were evaluated. The causes of clogging varied from location to location so that each site would require a different type of water treatment to prevent emitter clogging. Carbonate type materials were prominent in samples from the southwestern United States, whereas the microbial iron clogging substances were abundant in the samples taken in the southeastern region. The preceding factors, however, are not isolated to a specific region; instead, they have been observed within the same area and, of course, worldwide. Suspended particles have been blamed for most emitter malfunction, but they may participate only indirectly in the clogging process. Frequently, the small, suspended particles are caught by the filament and slime by-products of bacteria and increase in size to cause emitter plugging. Thus, the control of microorganisms would help greatly in alleviating emitter plugging.

A surprising observation during our investigations on determining the causes of emitter clogging was the presence of large quantities of microscopic to sand-size plastic materials obstruction emitter openings. The plastic cuttings originate from the sawing of the pipes during the installation, modification or repair of the drip system. This problem can be readily corrected by cutting the pipe or tubing with specially designed cutters that do not form plastic particles. When sawing is necessary, cleaning and flushing of the repaired sections before they are reconnected into the conveyance system can reduce plugging. Other unusual obstructions were the presence of oil and grease particles from leakage of bearing seals of well and booster pumps that are connected directly into the drip system. The obvious solution in this case is the proper maintenance of the lubricant seals. Also, the steel casing of wells was observed to be the source of dissolved iron, which is formed by iron-reducing bacteria. Emitter clogging prevention in such instance involves the control of the bacterial contamination or the use of plastic instead of steel casing.

A brief comment should be made on the presence of snails in the drip lines. The adult snails can be readily removed from the water by simple filtration. However, their eggs or larvae can pass through filters and eventually mature to the adult form in the irrigation line and cause restricted water flow in the emitters and larger-sized tubing. Other organisms that can pass the filters and undergo similar metamorphism or increase in population or size would also create clogging problems.

Root intrusion into emitter openings and tubing that restrict water flow has been observed for some types of buried tubing (Bui 1988; Kinoshita and Bui 1988). Emitter plugging in this case is not caused by irrigation water quality.

Water quality evaluation and classification

Based on the findings on emitter clogging and experience gained in controlling it, investigators have derived a classification scheme that included the major factors involved in emitter clogging. This is related to irrigation water composition (Table 2). Such a classification can be used as a guide for identifying potential clogging hazard as well as for selecting and designing water treatment systems. Little change in the classification scheme has been made since its proposal in the early 1980's.

Except possibly for microbial population analysis, measurements of suspended load and chemical composition can be made by the operator or most agricultural service laboratories. The effect of fertilizer or other chemicals on the irrigation water that may create clogging problems can be tested by the operator by treating the water with the additive (Gilbert and Ford 1986). Tests can be performed in the laboratory or office, independent of the drip system, so that the system will not be adversely affected if any negative results are obtained. Any fertilizer or chemical additive that increases the pH (alkalinity) of the water to the point where carbonate, phosphate or hydroxide can precipitate should be avoided.

Rolston et al. (1986) developed criteria for fertilizer application in drip systems. In their presentation, they consider the solubility of the fertilizer and the interactions of the fertilizer with the dissolve components in the irrigation water. Since then, acidified forms of nitrogen and phosphorus have become available (urea-sulfate and urea-phosphate), which have less tendency to cause pre-

Table 2. Water quality classification relative to its potential for drip emitter clogging (Bucks et al. 1979)

Clogging factors	Hazard rating		
	Minor	Moderate	Severe
Physical (mg/l)			
Suspended solids	<50	50–100	>100
Chemical (mg/l)			
pH	<7.0	7.0–8.0	>8.0
Dissolved solids	<500	500–2,000	>2,000
Manganese	<0.1	0.1–1.5	>1.5
Total iron	<0.2	0.2–1.5	>1.5
Hydrogen sulfide	<0.2	0.2–2.0	>2.0
Biological (no./ml)			
Bacterial number	<10,000	10,000–50,000	>50,000

cipitation problems than earlier fertilizer formulations (Mikkelsen and Jarrell 1987).

Waters with high concentrations of sulfide anions can cause iron precipitation. Iron and manganese sulfides are very insoluble even in acid solutions. The dissolved sulfide anion can also react with active chlorine when the water is chlorinated so that the effectiveness of the chlorination is reduced. Thus, the chlorination requirement of such water is higher than that of the typical non-sulfide irrigation water.

The water quality was also rated numerically for the classification scheme of Table 2 (Bucks et al. 1979), which was based on concentrations of the physical-chemical-biological factors. Although this approach gives a better picture of the clogging process it has not been widely used since detailed analysis of the water must be made.

Water treatment to control clogging

By knowing the causes of emitter clogging, preventive and control measures can be taken. In the early years of drip irrigation, operators were reluctant to spend money on water treatment chemicals and equipment because of cost and uncertainty regarding the reliability of such an operation. The initial cost of such material was significant relative to the cost of the emitters and supply lines, especially for small scale operations. The need for clean water has created a new sub-industry in irrigation water treatment to serve the drip user.

Physical treatment

Initially, water treatment equipment to remove suspended materials, whether screen or sand filters, or centrifugal separators, was adapted from other industrial applications. In many instances, the solid removal capacity was not adequate for the flow rate and suspended load encountered. Presently, such systems are designed and built to meet the needs of the specific drip irrigation operation. Filtration stations for any large operation are similar to a municipal water treatment facility. System capacity must match the suspended load of the water and flow volume, both of which can have wide variations throughout the irrigation management cycle. The media filters themselves can be automatically backwashed and arranged to that the backwash debris is removed from the system. Screen filters have self-cleaning features or built for ready dismantling or removal for cleaning and maintenance.

Many articles have appeared on the design, operation and maintenance of filter systems for drip irrigation. The American Society of Agricultural Engineers (1990a) has made recommendations for water filtration system design. The subject concerning filter types, selection, evaluation, performance, operation, and management has been adequately covered in various articles on this subject (Adin and Alon 1986; Bucks and Nakayama 1984; Bruce 1985; Farrel 1989; James and Shannon 1986; Pierce and Mancuso 1985; Zeier and Hills 1987). Wastewater filtration requires different consideration than the typical irrigation water source (Adin and Elimelech 1989). Reports on filtration and methods for improving operation and cost will continue to appear as long as drip irrigation systems are in operation (Anonymous 1990).

Filtration does not remove all suspended material and eventually sediments will accumulate in the tubing and emitter. Significant amounts of sediments were present in the laterals even with careful filtration (Shannon et al. 1982). Estimates on sediment accumulation patterns in the pipe line can be made (James and King 1984). Bui (1988) noted that there were more clogged emitters located at the end of the lines than at the beginning. Eventually, sediments must be flushed out of the lines. This should be done as part of the routine maintenance of the drip system. No specific guideline has been established regarding the frequency of line flushing. Flushing can be made on a daily, weekly or monthly basis depending upon the severity of sediment load. Checking the flush water for suspension is one way to determine sediment buildup. This procedure also can be used to check filter performance. Routine flow rate monitoring of the lines may also be used as a guide for flushing needs.

Removal of a portion of suspended particles using sedimentation ponds prior to water filtration can lessen the load on the filters (Nakayama 1986). A shortcoming with sedimentation ponds, however, is that they may create other filtration problems. Large algal population in the ponds can alter water quality as well as put added stress on the filtration system. Unexpected algal blooms due to environmental changes can overwhelm the filters. In such cases, the drip system may have to be shut down temporarily until the suspended load decreases to a manageable level.

Unfortunately, filtration is not the complete solution to the clogging problem. Small particles can pass through filter and emitters, but when they interact with microbial by-products such a combination can clog emitters. Other corrective measures, such as chemical treatment, are necessary.

Chemical treatment

Chemical water treatment in conjunction with filtration has become an integral part of drip irrigation systems, especially in large commercial operations. Chlorination is the most widely used chemical treatment to control microbial population. Larval organisms, which can clog emitters and decrease water flow when they become adults, can also be controlled. The principle of chlorination and the various types of chlorine sources for drip systems are discussed by Nakayama (1986). The question of whether to chlorinate continuously or intermittently (slug) cannot be adequately answered. There are merits for either methods, and the operator should select the one that fits the need of his system. Active chlorine concentration level (1 mg/l) is in the order present in municipally treated water for human consumption. No reports of damage to plants have been reported using water at such chlorine concentration. Any active chlorine present will be rapidly and completely deactivated by the soil materials. Plant damage caused by irrigating with chlorine-treated swimming pool water is caused primarily by the high concentration of salts in the water rather than by the active chlorine.

Water treatment using sulfuric or other acids still remains a reliable and widely used means for controling carbonate precipitation in drip systems. Procedures for estimating the tendency for carbonates to precipitate, based on chemical composition of the irrigation water, is available (Nakayama 1986). Titration of the water with dilute acid is a method for determining its acid requirement. Carbonate solubility decreases with increasing temperature (Nakayama and Bucks 1985) so that subsurface installation of the lines, where temperatures are moderated, may alleviate clogging. In some instances, where biological and suspended loads are low, such as an underground water source, acid treatment alone may be able to prevent emitter clogging.

Where acid treatment can adversely affect soil pH, other methods to control chemical precipitation must be used. An alternative to acid treatment is the use of compounds that will inactivate the heavy metal cations and prevent them from precipitating. Theoretically, any compound in sufficient quantities that will complex other ions with low solubility will keep them in the soluble state. The performance of such compounds must be tested under field conditions. Meyer et al. (1991) used the homopolymer maleic anhydride compound to complex calcium and magnesium cations so that the calcium and magnesium carbonates would not precipitate. Similarly, Schwankl and Prichard (1990) added phosphonate, which is an alkaline earth and heavy metal complexing agent. Ford (1977) observed other organic chemicals occurring in irrigation water, such as sulfonated lignin, can complex iron to keep it in solution.

Clogging resulting from iron precipitates is especially difficult to control. The presence of dissolved iron in natural water is usually caused by microbial activity. To complex soluble iron, Calder (1988) added sodium silicate to the irrigation water. However, this treatment is limited to water <10 mg/l iron and one low in Ca and Mg, since the high pH of the silicate solution would cause carbonate precipitation. Oxidation of the soluble, reduced form of iron to the insoluble oxide form prior to filtration is another method for removing iron from solution.

Chlorination, when the soluble iron is high (>0.4 mg/l), can cause large quantities of iron to precipitate. In such instances, chlorine injection should be made at a sufficient distance upstream from the filtration system to allow sufficient time for mixing, chemical reaction, and coagulation to take place before the iron flocculent reaches the filter for removal. Gamble (1985) introduced hypochlorite into wells containing high soluble iron content to control iron clogging. Aeration, to oxidize the soluble iron followed by sedimentation in a pond and filtration is another alternative (English 1985).

Emitter reclamation with chemical treatment is not practical nor economical since high concentrations of chemicals must be used. Unfortunately, the injected chemicals get to the good flowing emitters and not necessarily to the clogged ones, where their corrective action is suppose to occur (Nakayama et al. 1977; Meyer 1985). Thus, it is readily seen that clogging prevention is the key to the successful operation of a drip system.

A unique approach to biological control is to incorporate a chemical inhibitor with the plastic material of the drip emitter. Ruskin et al. (1990) and Van Boris et al. (1988) used this concept to control root growth into the emitter using an herbicide. Other chemicals to control insects could also be incorporated into the emitter and tubing materials. Further field evaluation of chemical inhibitors over time is needed.

Safety is a key part of chemical treatment. Proper precautions must be taken in handling and injecting chemicals into the irrigation lines. The American Society of Agricultural Engineers (1990 b) developed standards in the use of safety devices for applying liquid chemicals through irrigation systems. This include steps to prevent the injected chemical from flowing in the opposite direction for which it was intended, and the installation of interlocking devices which can stop the chemical injector from operating when the main irrigation flow has been drastically reduced or stopped.

As noted earlier, attempts have been made to build emitters with non-clogging, self-cleaning property. One approach is to use manual or automatic moving parts that are supposed to keep the water passages clear of obstructions. However, in practice, the automatic moving parts can be rapidly disabled when debris collects around the working parts. This either results in a decrease in flow or in some instances a large increase in flow rate when the cleaning mechanism is stuck in the fully open position. Mechanical cleaning of malfunctioning emitters is time consuming and experience has shown that such emitters will continue to operate poorly. Other self-cleaning emitters with flexing membranes tend to fail with time as the membrane material deteriorates from the various chemical added and biological activity occurring in drip system. Emitters with large pores to avoid the clogging problems can also fail when water of poor quality is used in them. If water can be adequately treated, emitters of any design with chemical and biological resistant properties should operate properly.

Selection of treatments

Before a new drip system is installed or and old one retrofitted for water treatment, chemical and physical analyses of the water should be made. If possible, a history of the water composition is desirable. Water samples may have to be taken several times over the year because water quality could change over the irrigation cycle. Also, if waters of different qualities are to be mixed, this mixture may need to be further evaluated as chemical and physical interactions may occur that can drastically change the quality of the resultant water. Based on the information listed in Table 2, potential clogging problems can be identified and the appropriate preventive measures taken. Equipment and chemicals needed for water treatment are now commercially available and a qualified irrigation designer can incorporate them into the system. The amount of equipment needed and the cost of treatment will depend on the initial water quality and the extent of water usage.

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