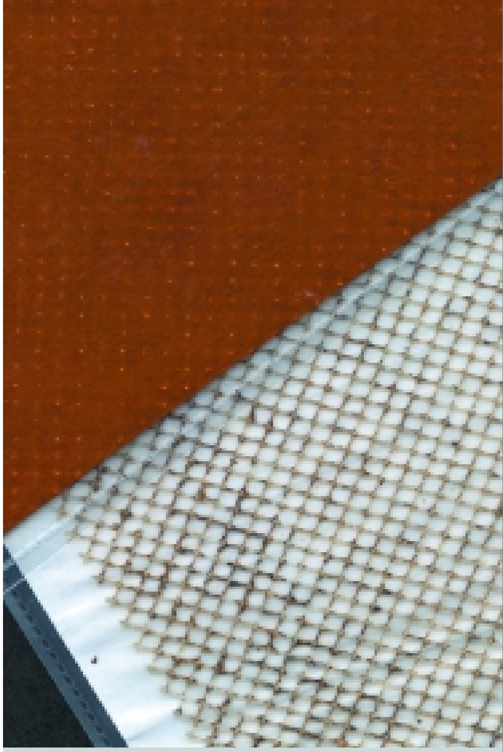

The Role of COAGULANTS in Reducing Particulate Fouling

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INTRODUCTION

Fouling by colloids and silt are the major causes of loss in performance of membrane separation systems.

Colloids are differentiated from silt by size and settling ability. Colloids are particles with approximate diameters of less than one micron which do not settle from suspension whereas, silt particles have an approximate diameter greater than one micron and they do settle.

Collectively, colloid and silt particles are termed particulates and these are present in virtually all feedwaters. Examples include clays, colloidal silica, rust particles, and bacteria.

Figure 1 illustrates the effect of particulate fouling on membrane system flow. The dotted line is flow from a system operating on a feed containing low levels of particulates.

The solid line illustrates operation on a feed that contains high concentrations of particulates. In both cases, effective cleanings are accomplished when the normalised flow decreases to 90% of the initial baseline value. However, in the case of the system operating on poor quality feedwater, cleanings are required three times as frequently. Production time is lost, plant operating costs increase, and membrane element life is reduced.

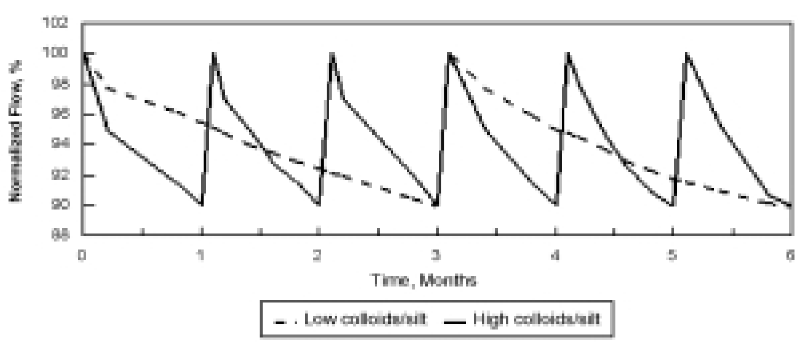
While there are effective cleaners for particulate fouling, it is far more economical to reduce the concentrations of these materials before they ever reach the membrane system.

PARTICULATE FOULING MECHANISMS

In reverse osmosis (RO), the convective force that is exerted by the permeate stream deposits particles onto membrane surfaces, forming a fouling layer or dynamic membrane. Counteracting this force is the shear exerted on this fouling layer by the feed-brine stream that tends to re-suspend deposited particles. Figure 2 on the following page illustrates the net effect of these forces.

Figure 3 shows the flux history of a membrane system that is undergoing particulate fouling. There is an initial phase in which flux decreases very rapidly with time. This is followed by a second phase characterized by a slowly decreasing flux. In the initial phase, a non-equilibrium condition exists characterized by a rapid rate of particle deposition that far exceeds the rate at which particles are re-suspended.

Figure 1
Effect of Colloids and Silt on System Flow



Over time, an equilibrium is established in which the deposition rate equals the rate at which particles are re-suspended. This latter phase is characterized by a flattening of the flux-time curve.

In the non-equilibrium phase, flux is proportional to net driving pressure and shear velocity and is inversely proportional to colloid concentration and time. Flux is also a function of the specific resistance and cohesiveness of the particulates. The following equation developed by Marshall Tulin of the Hydranautics Corporation relates these parameters.

$$Q_{non\text{-}eq} = \frac{NDP^{a}\ U^{*b}\ K}{C^{c}\ t^{d}}$$

where,

$Q_{non\text{-}eq}$ = Non-equilibrium flux
NDP = Net driving pressure
U^{*} = Friction velocity
C = Colloid concentration
t = Time
K = Constant that incorporates specific resistance and the cohesiveness of the particulates.
a,b,c,d = Exponents specific to the nature of the particulates

In the equilibrium phase, flux becomes independent of pressure and time:

$$Q_{eq} = \frac{K'\ {}^{*}\ U^{*a'}\ U_{b}^{b'}}{C^{c}}$$

where,

Q_{eq} = Equilibrium flux
U_{b} = Particle binding force

Most RO desalting processes operate in the non-equilibrium mode. When particulate concentrations are low, relatively long service runs are possible before cleaning is required.

For RO system operation, flux is increased by increasing the net driving pressure. However, a doubling of net driving pressure seldom results in a doubling of flux. This is because the "a" exponent in the non-equilibrium equation is always less than one. Rearrangement and differentiation of the non-equilibrium flux expression gives the following equation:

$$\frac{dNDP}{dt} = \frac{d/a\ {}^{*}\ (Q^{1/a}\ {}^{*}\ C^{c/a})\ {}^{*}\ t^{(d/a\ -\ 1)}}{K^{1/a}\ {}^{*}\ U^{*b/a}}$$

This equation states that to maintain a constant flux, net driving pressure must be increased with time because of particulate fouling (a fact well known to designers and operators of RO systems).

Further inspection of the equation suggests several means of reducing the rate of particulate fouling (limiting the rate of increase in the term). These include:

1) reducing system design flux
2) increasing system feed-brine velocity
3) reducing feedwater particulate concentrations
4) chemically altering the nature of the particulates to make them less cohesive.

Equipment manufactures routinely incorporate (1) and (2) into their equipment designs. The addition of multimedia filters to the pretreatment scheme also reduces particulate concentrations. To reduce the cohesive nature of particulates that escape the filtration process, antiscalant-dispersant formulations are employed. (Please read the Avista technical bulletin entitled Antiscalants for additional details regarding the function and use of these formulations.)

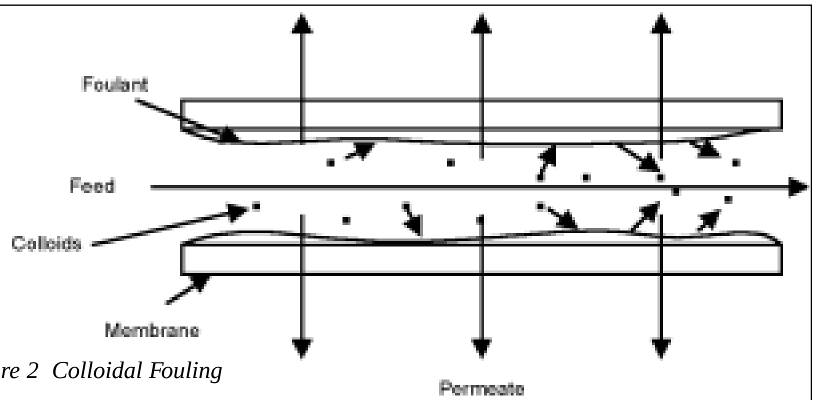
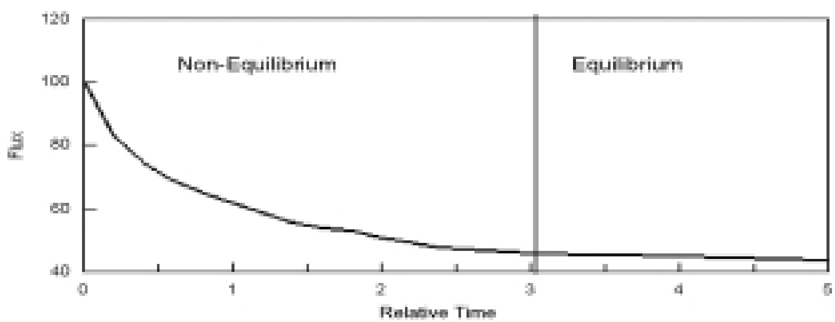


Figure 2 Colloidal Fouling

Figure 3 Flux History



The following section gives more details on the multimedia filtration process and the use of coagulants.

FILTRATION

Multimedia filtration is usually the most economical means of removing particulates from the feedstreams of RO systems.

However, to operate efficiently, multimedia filters must be dosed with coagulants. Without coagulant or flocculant addition, multimedia filters are capable of only 35% to 50% particulate removal in the <2 micron range.

A myth exists that coagulants, especially organic coagulants, chemically foul thinfilm RO membranes. Both field experience and exhaustive laboratory testing have demonstrated unequivocally that when dosed properly, coagulants do not chemically foul thinfilm membranes. Rather it is the gross overfeeding of pretreatment chemicals and the feeding of incompatible mixtures of chemicals that usually cause chemical fouling of RO membranes.

There are of two basic types of coagulant/flocculant:

1) Metal salts that include alum (aluminum sulfate), ferric chloride, and ferric sulfate. Added to water, metal salts go through a series of hydrolysis reactions that result in the production of positively charged metal-water species.

2) Organic molecules, constructed to contain charged groups are the second type. These coagulants have high charge densities and molecular weights that range from about 70,000 to 500,000.

Both types of filter aid are used widely. The following describes the mechanism by which coagulants work.

FUNCTION OF COAGULANTS

Multimedia filtration involves a variety of complex mechanisms to achieve particle removal. These particles are generally much smaller than the size of the interstices between filter grains. Transport mechanisms are needed to carry the small particles into contact with the surfaces of the individual filter grains where attachment mechanisms then hold the particles.

Transport mechanisms include gravitational settling, diffusion, interception, and hydrodynamics that are affected by such physical characteristics as size of the filter medium, filtration rate, fluid temperature, and the density, size, and shape of the suspended particles.

As particles approach the surface of a media grain, short-range electrostatic forces begin to influence particle movement. Most naturally occurring particles, including the filter media, possess negative electrostatic charges or zeta potentials. Negative charges present on both particles and filter media work in opposition to the transport mechanisms.

When added to the feedwater, coagulants neutralize the negative electrostatic charges on both particles and filter media surfaces. Elimination of these charges makes collisions and attachments between particles and media grain surfaces possible.

It is important that coagulants be fed at their optimum dosage. Overfeeding of coagulants, especially organic coagulants, results in positive electrostatic charges on both media surfaces and

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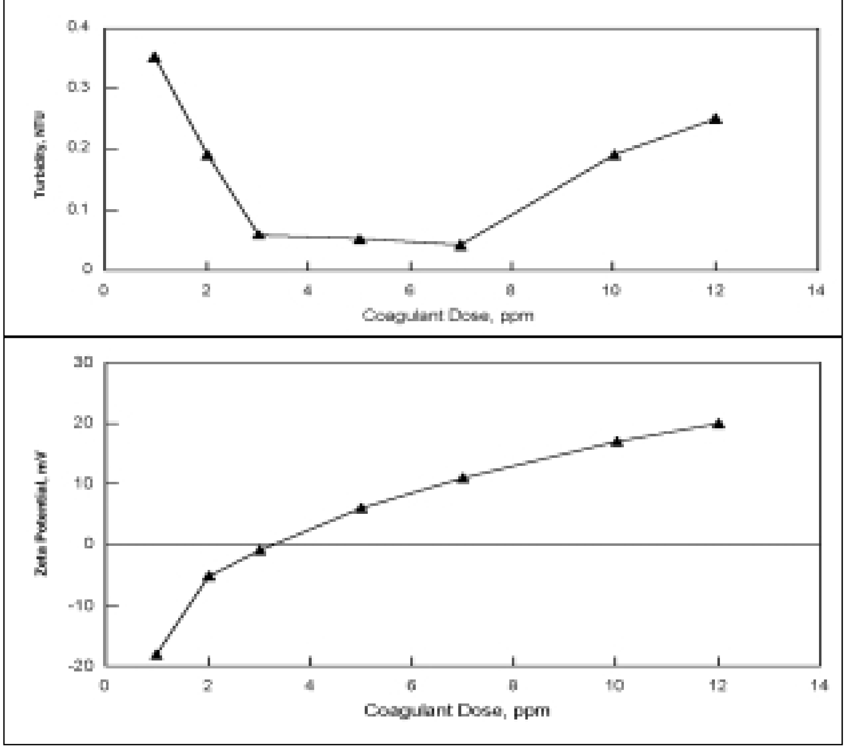
Figure 4

Affect of Coagulant Dose



particulates. Positive charge on media and particulates has the same detrimental affect on filtration as does negative charge. Figure 4 illustrates the importance of proper dosing.

For direct filtration applications (raw water turbidity values less than about 10 NTU), coagulants are added in-line directly ahead of the multimedia filters. When the raw water turbidity is very high, flocculator-clarifiers generally precede multi-media filters.

These are large mixing and settling chambers designed to remove most of the particles contained in the raw water, thus reducing the solids loading on the filters located downstream. A goal of RO pretreatment is to reduce the turbidity of the feedwater to less than 0.2 NTU. For most waters, this value is impossible to attain through multimedia filtration without the use of coagulants.

To support the designers and operators of RO equipment, Avista carries a complete line of coagulant products developed specifically for RO pretreatment. Avista personnel are trained in the use of these products and in the troubleshooting of clarification and filtration processes.

ECONOMICS OF COAGULANT ADDITION

Plant operating costs are directly proportional to cleaning frequency as shown in Figure 5.

The partial operating costs used in this figure are based upon a 100 gpm plant operating at 75 % recovery. Cost items include membrane elements, cartridge filters, chemicals for ion exchange regeneration, and the labor required for cleaning. (Ion exchangers are used for permeate polishing.) Not included in the partial cost analysis are electrical and scale inhibition costs, as these items are common to each of the cleaning frequency cases.

Figure 5 shows that operating costs decrease rapidly with decreases in cleaning frequency. Operating costs begin to plateau when the cleaning frequency reaches about once every three months. The minimum operating cost occurs at a cleaning frequency of about once in nine months.

When membrane fouling is due chiefly to particulates, the use of coagulants to improve the efficiency of multimedia filtration can dramatically decrease cleaning frequency. The cost savings that can be obtained by coagulant addition is illustrated by the following typical example:

A 100 gpm plant operating without coagulant addition requires monthly cleanings, resulting in an operating cost of $6,367 dollars per month. The same plant operating with the addition of 5 ppm of coagulant needs cleaning only quarterly, resulting in a monthly operating cost of $3,490 dollars. In this case, the addition of coagulant results in a cost savings of 45%.

COAGULANT CHOICES

Avista currently produces a range of coagulant and coagulant/flocculant formulations. Each is compatible with thinfilm membranes, however, these and other coagulants may not be compatible with all antiscalants.

It is important to use only coagulant compatible antiscalants-dispersants such as Vitec 3000 or 5000. A brief description of Avista Coagulants products and their application guidelines are included in Avista Technologies Coagulant Selection datasheet.

The selection of the most effective coagulant/flocculant and its optimal dose rate is normally made through plant trials or laboratory jar test procedures. Please consult the Avista for details.

Please consult Avista Technologies for information on, and assistance with, selecting the optimum coagulant dosage for your system.