Designing For Success

Weighing the consequences important in system design.

By C.F. "Chubb" Michaud

It takes considerable experience and engineering skills to design a water treatment system that will do the job at minimum cost. There are, however, two costs involved in a system design, capital costs and operating costs. Minimizing capital costs may necessitate very high operating and replacement costs. Minimal operating cost designs may be prohibitive capital expenditures. The correct design lies somewhere in between.

Traditional water treatment design dictates conservatism. Standard engineering factors are applied which allow for overbuilding. These safety margins assure that the particular piece of equipment will still perform its function even after it has deteriorated slightly due to age (usually three years) or the total dissolved solids (TDS) goes up 10 or 15 percent.

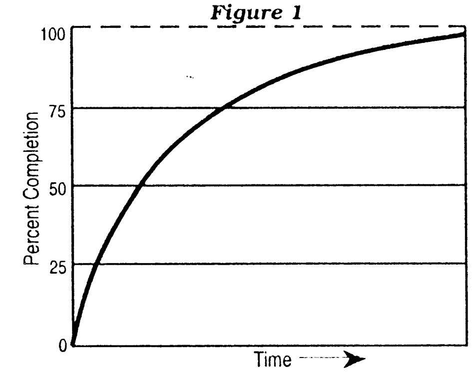
Historical Design

Years ago, the only types of filters employed were low pressure sand filters and even gravity filters. These were used to reduce turbidity and suspended solids, and they operated at flow rates of about 6 gpm per square foot of bed area. About the turn of the century, when natural zeolites were discovered to remove scale-causing hardness, these "minerals" were substituted for one of the sand layers in the same equipment.

Bed depths and flow rates were maintained, and the industry began to develop around a set of operating parameters established for a totally different need from a totally different era. Still later, synthetic zeolite and finally, ion exchange resins came into existence, replacing natural zeolites and using the same operating conditions.

Although the first "modern" ion exchange resins (circa 1941) were styrene/di-vinyl benzene (S/DVB) of essentially identical composition as today's, they really weren't as good as their current heirs. Resins with whole perfect beads weren't necessary. After all, they were replacing highly irregular, granular materials, so a fractured resin was no great detriment.

Figure 1



These systems ran very well at 6-8 gpm/ft^2, producing low leakage and high capacities on 8-10 lb. salt/cubic foot regeneration levels. There were no restrictions on dumping brine and no need to conserve. High pressure boilers were unheard of. Purified water came from distillation. The miniaturization of these water softeners created a booming new industry for residential use. The rest is history.

From this point on in the development of water treatment equipment, there came a departure in technology. Equipment intended for municipal and industrial applications continued to be designed on the conservative side with safety margins. On the other hand, equipment designed for residential use pushed the evolving technology to the limit. The relative ease of entry into the residential water conditioning market and the resulting competitiveness of the business has given birth to the modern domestic softener — a highly engineered, effective and yet affordable appliance for today's home.

Softener manufacturers (with the help of tank, resin and valve manufacturers) have engineered the home water conditioner to the very edge of its performance envelope. All the "fluff" and most of the safety margin have been removed for the sake of cost. Today's home water softener is probably the best-engineered piece of water treatment equipment on the market. It is inexpensive for the job it does, but not "cheap," and it is highly effective.

Today, many manufacturers of home water conditioners are attempting to cross over to the industrial and commercial side of the business (which continues to remain conservative in design). Many of the new applications involve more than the removal of hardness. Nitrate, fluoride, arsenic, toxic organics and heavy metal removal, for instance, carry with them certain health related benefits that must be substantiated with broad safety margins.

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In other words, the highly evolved water softening technology is not transferable, although the equipment used for it is. The secret to the successful transition lies in proper design with adequate safety margins.

Designing for Success

Water treatment practices fall into two broad categories: mechanical and chemical. Mechanical treatments involve filtration, reverse osmosis and even distillation. Here, treatment involves the movement of water from one place to another while "straining out" impurities. Such treatments are *not strictly a time-related reaction* (although flux rates do affect ultimate quality). On the other hand, ion exchange, carbon adsorption and disinfection *are time-related reactions*.

In other words, there is a certain amount of time needed for the desired change in the water chemistry to occur. Therefore, the proper equipment design must be adequate to allow sufficient contact time for the reaction to take place. Too small a system will result in insufficient dwell time and an incomplete removal. Too large a system would be wasteful.

There are two major aspects of "safe" design: the rate of reaction, or *kinetics*, and the *consequences of failure*.

Kinetics

The rate at which a chemical reaction (such as ion exchange and carbon adsorption) takes place depends on the type and concentration of contaminant, the temperature, the pH, the condition of the exchange or adsorption media and the presence of other interfering ions or adsorbates.

A big factor is concentration. For example, to soften water with ion exchange, a hardness ion in water must have sufficient driving force (concentration) to force diffusion into the resin bead. This, of course, will also depend upon how much hardness ion is already present inside the bead. Then, a sodium ion from inside the bead must diffuse out of the bead into the water. This is also dependent upon the concentration of the sodium within the bead as well as the sodium concentration in the water.

Equilibrium

Dealers who have tried to soften very high TDS water and ended up with high hardness leakage have firsthand experience with a phenomenon called *equilibrium*, which changes the rates of reaction and therefore the kinetics. A simple explanation is to picture what goes on

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inside a softener. The highest concentration of hardness (and therefore the highest driving force) occurs as the water first passes throughout the resin, and hardness is reduced while sodium or potassium increases. The driving force is therefore decreased. The next increment of hardness removal takes a little longer because the driving force is less (and the driving force of the sodium ion trying to diffuse into the water, which is increasing in sodium concentration, is also less).

Therefore, it takes longer to remove the second half of the hardness than the first half. This basic "driving force/kinetic" relationship holds true for all ion exchange and is graphically represented in Figure One.

As the reaction proceeds, it takes longer. With activated carbon, there is a "half-length" of reaction. Simply stated, if it takes 30 seconds to remove 50 percent of a contaminant, it will take an additional 30 seconds to remove 50 percent of the remaining 50 percent (to 75 percent), 30 more seconds to remove 50 percent of the remaining 25 percent (to 87.5 percent) and so on. Getting any given contaminant down to a 99.99 percent removal, therefore, dictates conservative design. The need to do so will be governed by the consequences of failure.

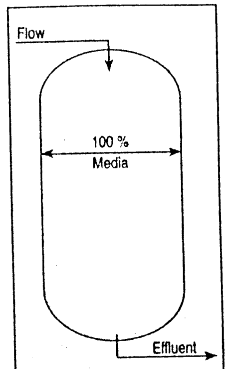


Figure 2
Typical Column

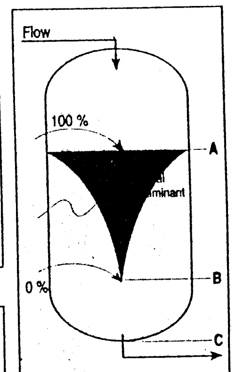


Figure 3
Operation

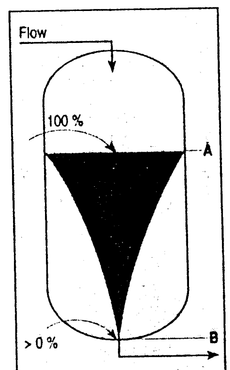


Figure 4
Breakthrough

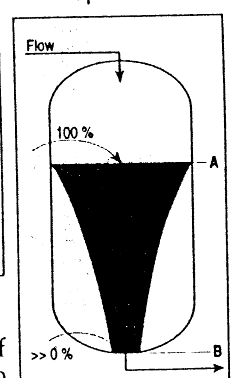


Figure 5
Slippage/Exhaustion

Figures Two through Five show what occurs inside a column as water passes from top to bottom. Figure Two represents an ion exchange or GAC column, and the diameter of the column represents the full contaminant level. As water flows down through the column, the contaminant level is reduced further until the reaction is complete (Figure Three).

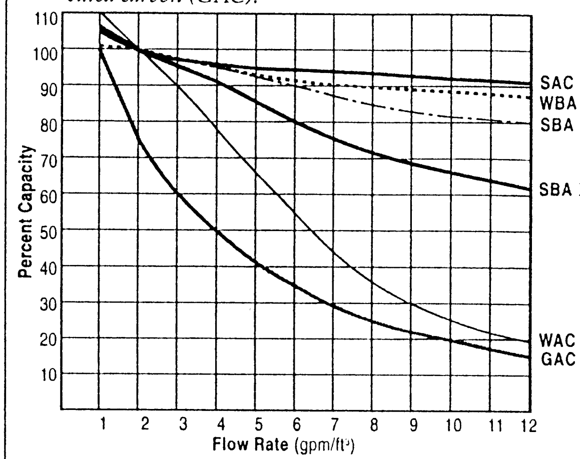
In passing from Point A to Point B, the contaminant level decreases from 100 percent to 0 percent. The remaining capacity of the column is represented by the media depth between Points B and C. Figure Four shows breakthrough.

If it takes X number of seconds (or minutes) for the reaction between Points A and B to occur, then too heavy a flow will have leakage (actually blow-through, bypass or slippage) from the very beginning (Figure Five).

Whether or not it would be proper to operate the column shown in Figure Five will depend on what is shipping. How dangerous or harmful is it?

Figure 6

The flow rates of strong acid cation (SAC), weak acid cation (WAC), strong base type I (SBAI), strong base type II (SBAII) and granular activated carbon (GAC).



The Consequences of Failure

The industry standard for the typical home water softener is a one cubic foot unit, rated at up to 30,000 grains capacity with 8-10 lbs. of salt and flow rates up to 10 gpm. According to the literature generally used for commercial and industrial design, this unit would be expected to deliver 22-24 Kgrains capacity in 500 ppm feed water with 13-15 grain hardness and have leakage no greater than 4-5 ppm.

As the TDS approaches 1000 ppm, the capacity drops by about 1 Kgr, and the leakage goes to 12-15 ppm — still less than one grain. The sacrifice for the relatively high flow rate (10 gpm/ft) is slight — only one Kgr less than at two gpm/ft^3. Today's resins are stronger and have higher perfect bead counts, so flow rates of 15-20 gpm/ft^2 pose no real threat to bead integrity. Unless pressure drop is a problem (about 6-8 psi at max. flow), this is an acceptable design and, other than the overestimate of capac-

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ity, will perform well.

In assessing the consequences of failure, it seems clear that there are really no big problems. Even with leakage of one grain, the worst thing that might happen is an occasional water spot. Many areas of the country would consider one grain of hardness "naturally soft" and not requiring treatment. Besides, many people living in areas with 10 grains of hardness get by without water conditioners and no ill effects, aside from the obvious inconvenience of hard water.

A dealer designing a softener for a moderate pressure industrial boiler would not simply upsize this unit for the higher flow. For one thing, leakage of hardness above one ppm would have to be avoided for fear of scale buildup, loss of heat transfer, and subsequent down time and maintenance expense.

To guarantee <1 ppm leakage, 20 lbs. of salt would be required on 500 ppm influent, and counter-current regeneration would be required on 1000 ppm feedwater. Real counter-current requires that the bed be held in place during regeneration (with water block or air block flow) and infrequent backwashes (requiring better prefiltration). A 38 cu. ft. bed (48 in. dia.) would handle 100 gpm flows for approximately 11 hours at 500 ppm (50 percent hardness) and 5.5 hours at 1000 ppm (with 50 percent TH). For continuous operation, at least two units would be required.

Is five hours enough time to make up brine? Are two brine tanks required? How is the cycle time determined? How does the dealer test? On-line monitors, perhaps? That's expensive. Certainly, the design considerations will change because of the *consequences of failure.*

So far, all this concerns is a softener for an industrial boiler. What about the consequences of failure when dealing with nitrate or lead removal, or THMs and PCBs, or other health-related processes?

Table 1

Media	Application	Flow/ft	Efficiency
SAC	Softening	6 – 10	97%
SAC	Softening	2 – 3	99%
SAC	D.I.	1 – 2	99%
WAC	Lead (H+)	25 – 30	5%
WAC	Softening	2 – 4	99%
WAC	Alkalinity Reduction	2 – 4	97%
SBA II	Nitrate	2 – 3	95%
SBA II	Nitrate	6 – 8	70%
SBA II	Alkalinity	1 – 2	95%
SBA II	Alkalinity	2 – 4	90%
WBA	Acid Neutralizer	6 – 8	98%

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Prudence dictates that these situations be studied very carefully to get all the facts. Size the system with sound engineering practice and conservatism of design. Big is beautiful.

Re-Designing For Success

While it is possible to press a home water conditioner into double duty by piggybacking some other filter media, such as GAC or sand with it, the expectations of what the added benefit really is must be kept reasonable. Do not assume that a certain media will continue to do the job at any and all relative flow rates, simply by its presence. As was pointed out earlier, filter media such as ion exchange resin and GAC are flow-rate dependent. The faster they are pushed, the less a dealer can expect.

A quarter cubic foot of anion on top of one foot of cation run at 7 gpm sees 28 gpm. This is 14 times the recommended flow. Five pounds of GAC (about 1/6 of a cubic foot) would show an empty bed contact time (EBCT) of only 10.7 seconds at 7 gpm. When is the dealer going to change it out? Better yet, how? At that flow rate, its capacity would be exhausted in less than a month. Municipal GAC systems designed for the removal of ppb levels of VOCs are often built with EBCTs of 20 minutes. GAC change-outs occur every one or two years.

Does all of this mean that a water treatment professional should abstain from the ever-growing opportunities of the health-related marketplace? Not at all. Simply design for success.

Figure 6 and Table 1, which gives design parameters for a variety of filter media applications, show the approximate loss of capacity for the various filter media as flow rate is increased. This information can be interpreted primarily as a loss of capacity with only a slight increase in leakage performance. In addition, it may be necessary to increase regenerant levels slightly to maintain leakage. Some resins, particularly GAC, are sensitive to flow rate (Figure 6).

Prudent engineering design dictates conservatism in sizing water treatment equipment. The more serious the design application, the more conservative the allowances for error. Dealing with health-related claims and critical performance applications (i.e., 99.99 percent removal) indicates a need for pilot study. Successful designs work. Design for success ❑

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