Water Softening with Ion Exchange

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RESINTECH INC.

INNOVATIONS IN ION EXCHANGE

Agenda Topics

- Water Softening Terms
- How Softeners Work
- Softener System Design
- What Can Go Wrong

Part 1: Water Softener Terms

"The ion exchange water treatment industry is bedeviled by the most complex and illogical set of units ever devised by the wit of man."

~ T.V Arden, 1968

Definitions

Cations
Positively charged ions dissolved in solution

+

Anions
Negatively charged ions dissolved in solution

−

Common Ions Found In Water

Cations

Calcium Ca^{++}

Magnesium Mg^{++}

Sodium Na^{+}

Potassium K^{+}

Iron Fe^{++}

Manganese Mn^{++}

Anions

Sulfate SO_4^{--}

Chloride Cl^-

Alkalinity HCO_3^-

Water Analysis Terms & Units of Measure

Helpful Standards & Equivalents

PPM (mg/l) or Parts Per Million (milligrams per liter)

PPM (as CaCO3) / 17.1 = gpg

“Grains” per cubic foot (or kilograins, Kgrs/cu.ft.)

7000 Grains = 1.0 pound

"as $CaCO_3$” or "as Calcium Carbonate Equivalents"

Part 2: How Softeners Work

- Ion Exchange Basic Theory
- Characteristics of Softening Resins
- Selectivity for Hardness Changes with TDS
- Operating Capacity and Hardness Leakage

Simplified Ion Exchange Theory

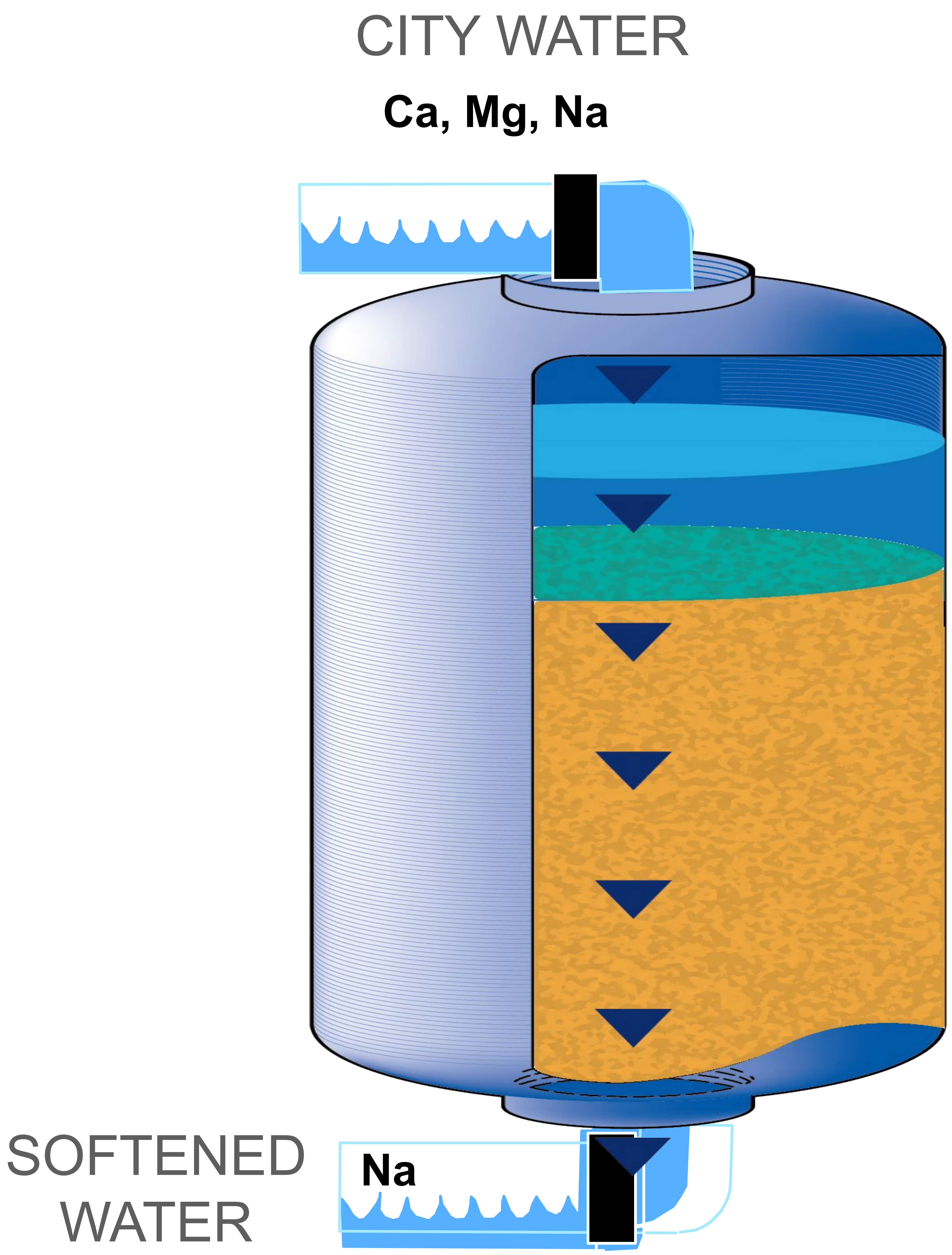
Ion exchange resins are **plastic beads** that **take ions out of water** and **put other ions back in.**

In this case, exchange the hardness ions **(calcium and magnesium)** for sodium (Na^+) ions .

How a Softener Works

Making "Soft" Water

- Hard water enters the vessel and is distributed across the resin bed
- Calcium and magnesium ions are exchanged with sodium ions
- Sodium ions are very soluble
- All scale forming ions are removed



Why Water Softening is so Efficient

- **Favorable selectivity for hardness** when TDS is relatively low
- **Low leakage** even when resin is almost exhausted
- **Chemical efficiency** can exceed **90%** (5,500 grains per pound of salt) when brine concentration exceeds **10%** (roughly 100,000 ppm as $CaCO_3$)

Hardness vs Sodium

An exchange where concentration matters

Hardness vs Na	100 ppm TDS as $CaCO_3$	1,000 ppm TDS as $CaCO_3$	100,000 ppm TDS as $CaCO_3$
CG8 preference for hardness compared to sodium	2,500	250	2.5

Characteristics of Softening Resins

Physical Properties	
Size	0.3 to 1.2 mm (16 to 50 mesh)
Weight	50 lbs. / cu.ft.
Density	1.28
Max temp	250℉ (120℃)

Characteristics of Softening Resins

Chemical Properties	
Capacity	44,000 grains/cu.ft. total
% of DVB	Approximately 8
Type	Strongly acidic, cationic
Matrix	Sulfonated styrene divinylbenzene copolymer
Ionic Form	Sodium (neutral salt)

Types of Strong Acid Cation Resins

Standard Cation

- 8% crosslinked, industrial quality
- Light or dark color

High crosslinked cation

- 10% crosslinked
- More resistant to oxidation

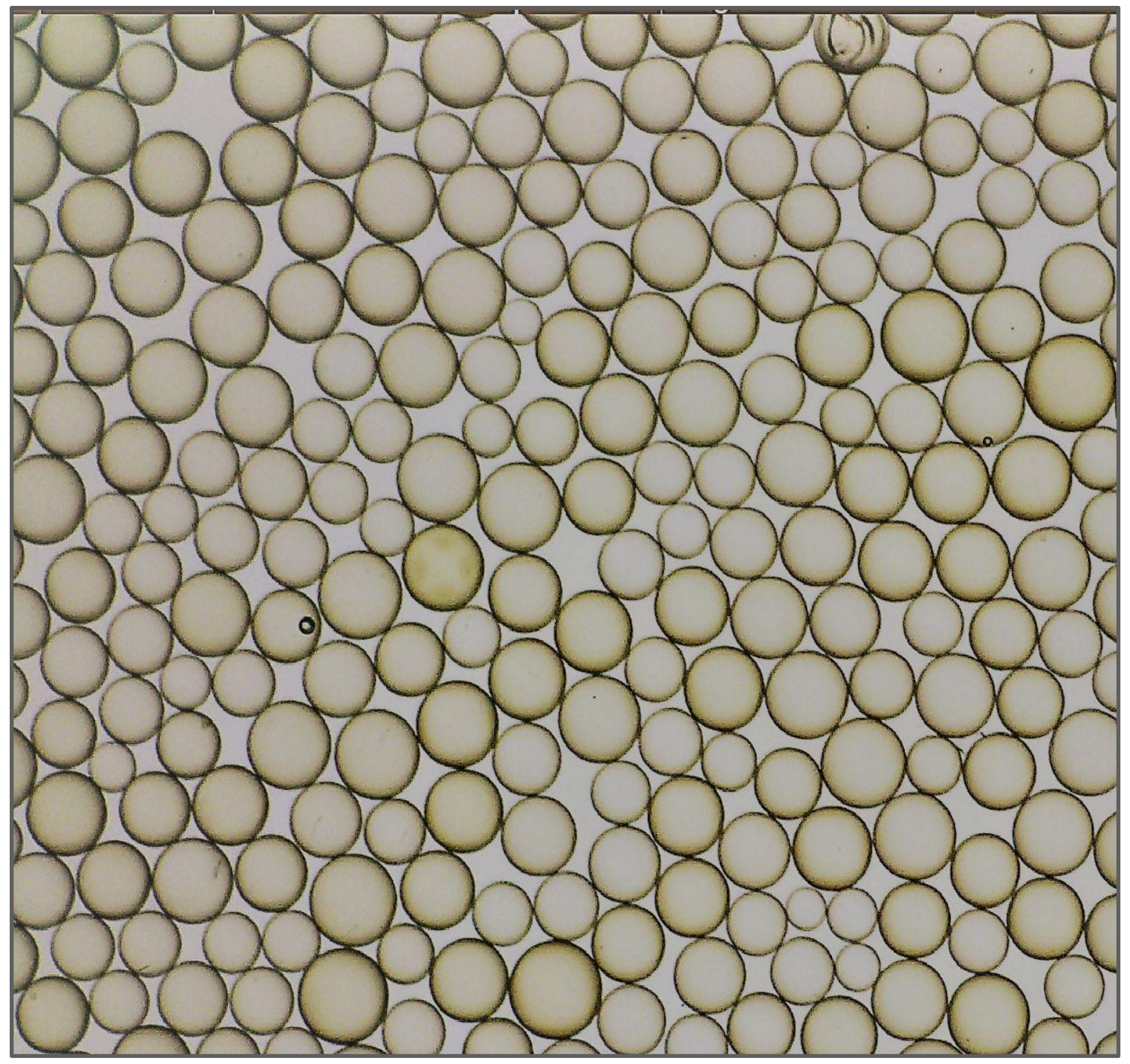
Macroporous Cation

- Physically toughest

Specialty Cation Resin Sizes

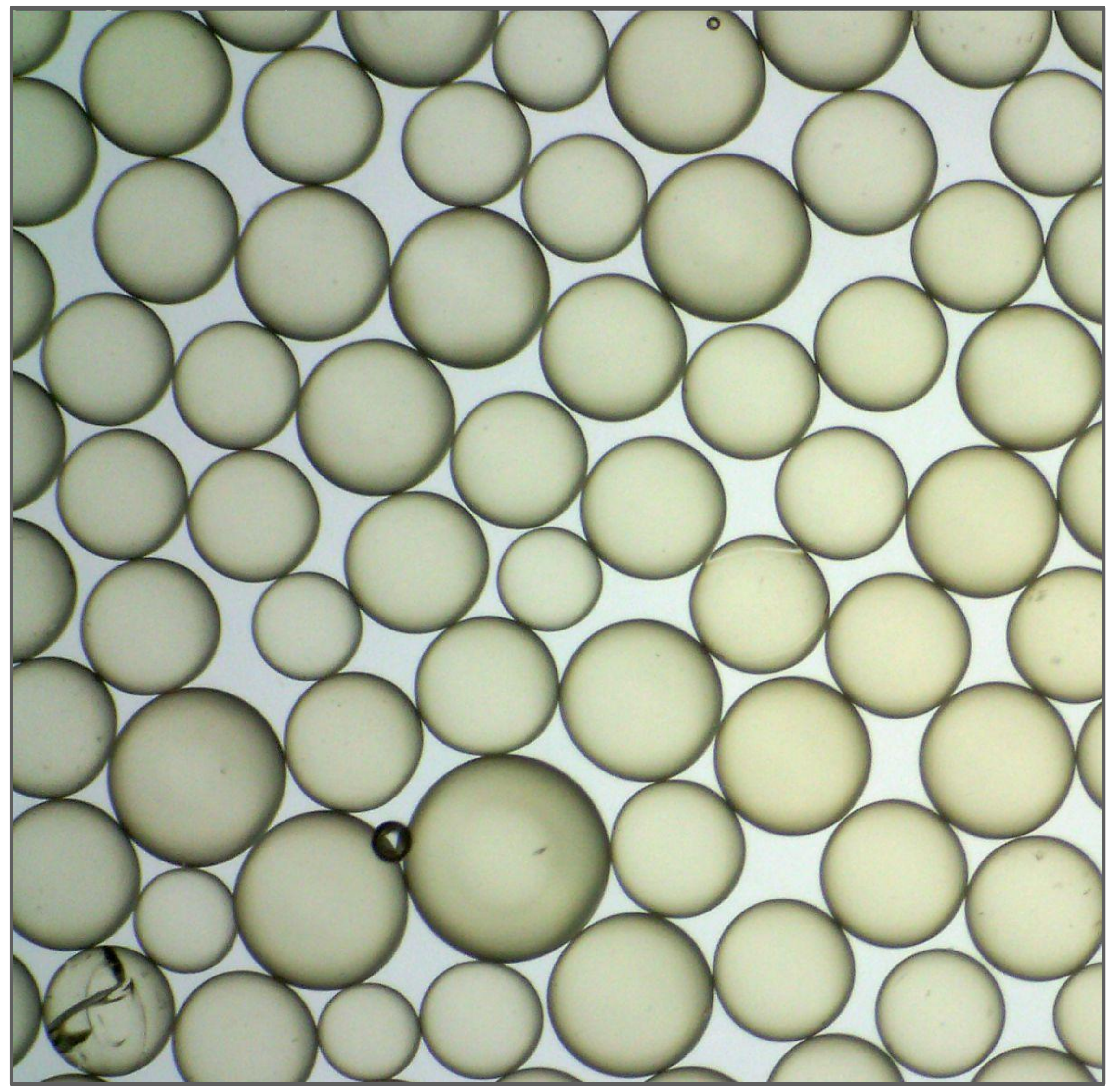
Fine Mesh

- Usually 30 to 60 mesh
- Greater surface area
- Shorter path to bead center
- Slightly higher capacity / brine efficiency
- Also useful in iron containing waters



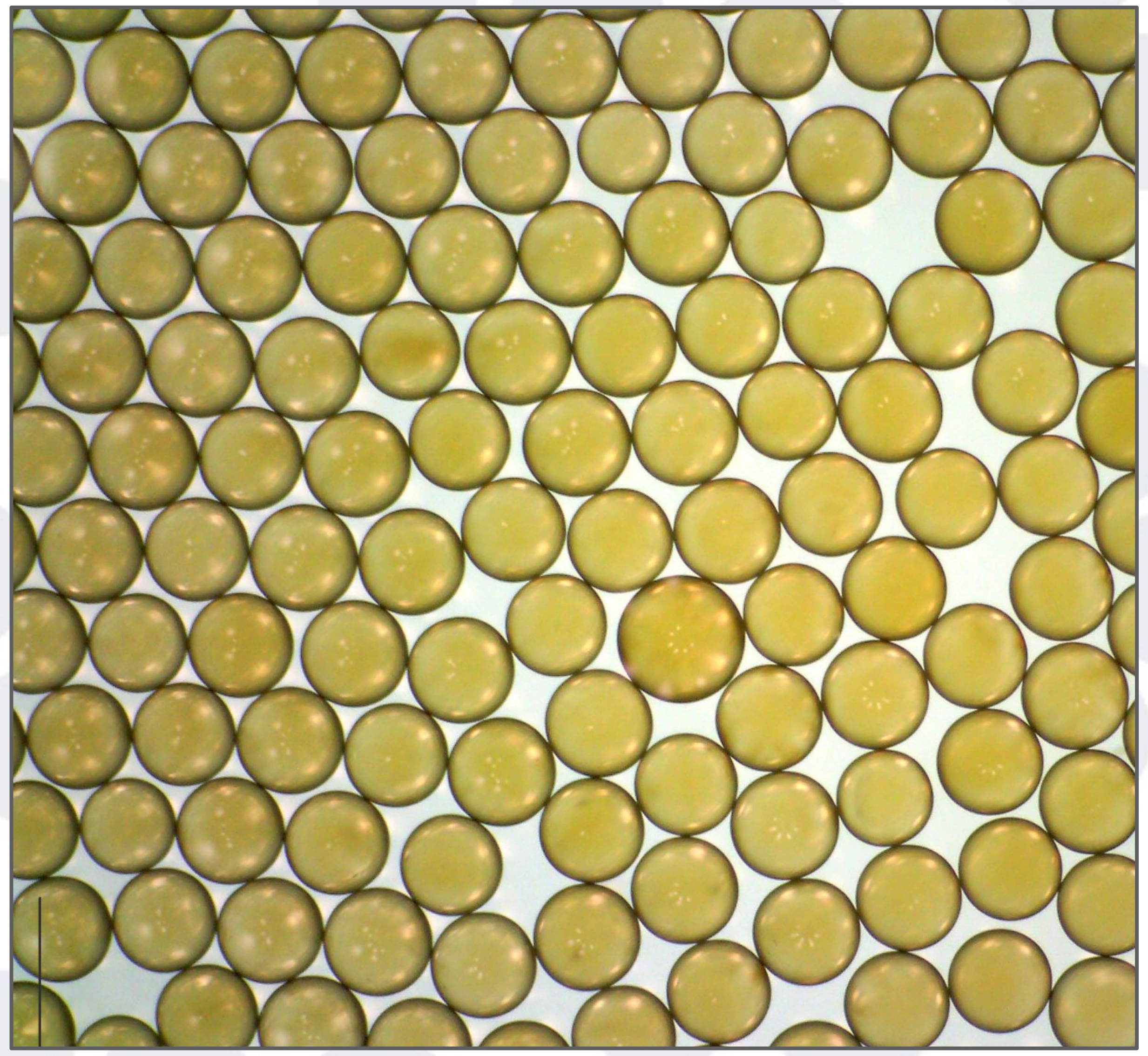
Coarse Mesh

- Usually 16 to 30 mesh
- Lower surface area = lower pressure loss
- Slightly higher flow rates through the resin bed



Uniform Particle Size

- Commonly used in packed beds



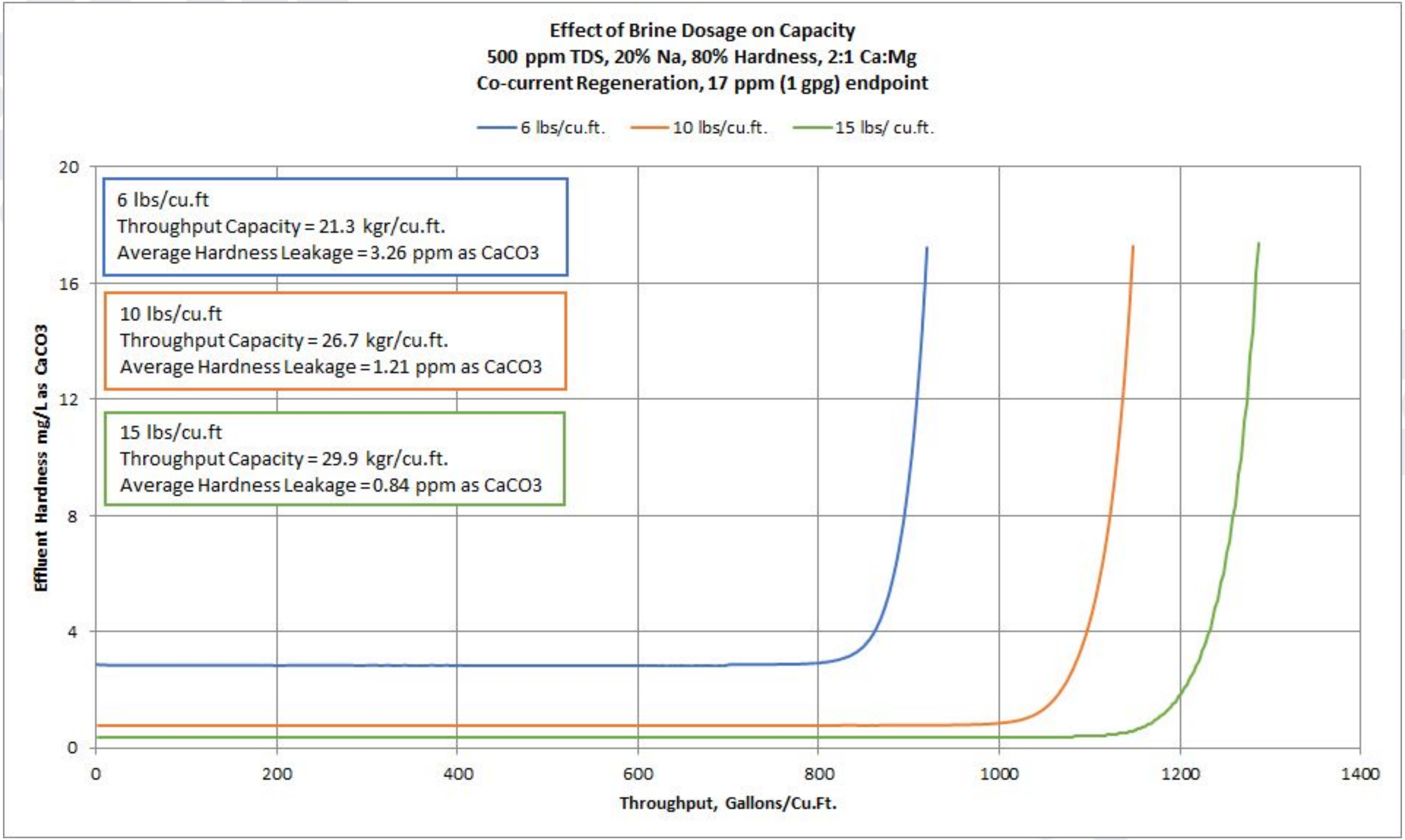
Capacity and Leakage Rules of Thumb

Commercial Softening Systems

Salt Dose lbs/cuft	Avg. Capacity kgrns/cu.ft	Avg. Leakage ppm (as $CaCO_3$)
6 lbs	22 to 24	5 to15
10 lbs	27 to 30	2 to 7
15 lbs	30 to 33	1 to 3

Notes:

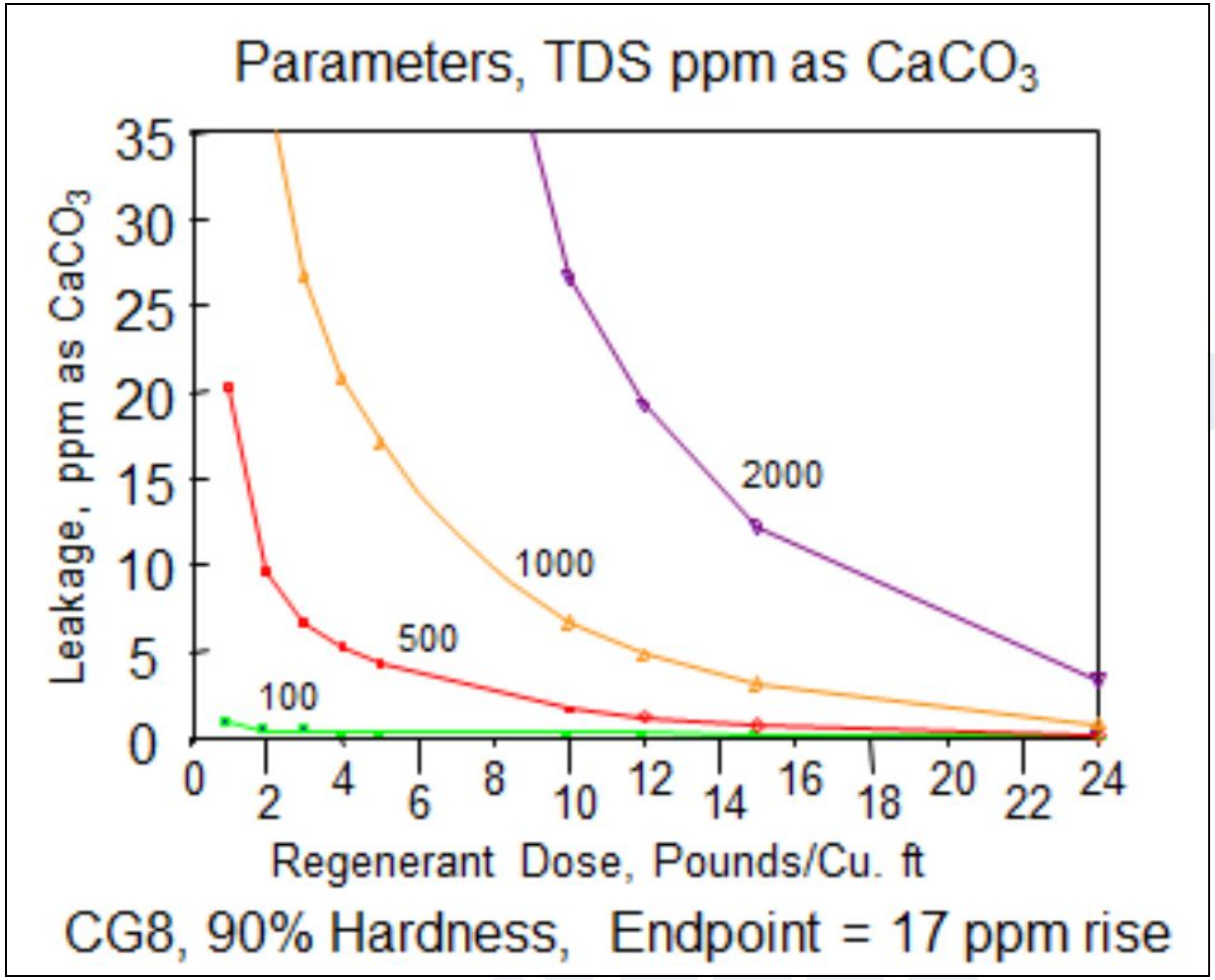
- *Capacity and leakage values are averages for 8% DVB gel type (virgin resin)*
- *The higher capacities and lower leakages are based on a TDS of 400 ppm*
- *The lower capacities and higher leakages are based on a TDS of 1200 ppm*



Effect of Brine Dosage on Capacity
500 ppm TDS, 20% Na, 80% Hardness, 2:1 Ca:Mg
Co-current Regeneration, 17 ppm (1 gpg) endpoint
6 lbs/cu.ft.
10 lbs/cu.ft.
15 lbs/ cu.ft.
6 lbs/cu.ft
Throughput Capacity = 21.3 kgr/cu.ft.
Average Hardness Leakage = 3.26 ppm as CaCO3
10 lbs/cu.ft
Throughput Capacity = 26.7 kgr/cu.ft.
Average Hardness Leakage = 1.21 ppm as CaCO3
15 lbs/cu.ft
Throughput Capacity = 29.9 kgr/cu.ft.
Average Hardness Leakage = 0.84 ppm as CaCO3
Effluent Hardness mg/L as CaCO3
0
4
8
12
16
20
0
200
400
600
800
1000
1200
1400
Throughput, Gallons/Cu.Ft.

Hardness Leakage vs TDS vs Salt Dose

- Higher TDS = lower preference (increased leakage)
- More salt = reduced leakage
- For new systems, consider countercurrent regeneration to improve leakage




Comparison of Co-current and Counter Current Regeneration
500 ppm TDS, 20% Na, 80% Hardness, 2:1 Ca:Mg
Regenerating at 10 lbs/cu.ft NaCl at 10%
Co-current
Counter Current
Co-current (10 lbs/cu.ft)
Throughput Capacity = 26.7 kgr/cu.ft
Average Hardness leakage = 1.21 ppm
Counter Current (10 lbs/cu.ft)
Throughput Capacity = 28.8 kgr/cu.ft
Average Hardness leakage = 0.68 ppm
Effluent Hardness mg/L as CaCO3
0
4
8
12
16
20
0
200
400
600
800
1000
1200
1400
Throughput, Gallons/Cu.Ft.

Part 3: Softener System Design

- Residential vs Commercial vs Industrial Systems
- Practical Limits for Sizing
- Regeneration
- Salt Efficiency and Waste Volume

Defining the System by Application

Residential/Household units

- High peak flow compared to average flow
- Intermittent usage
- Pipe size ¾” max
- Most tanks are prefab plastic
- Resin bed depth limited by tank availability
- Salt efficiency of increasing importance
- Color, taste, and odor important

Defining the System by Application

Commercial

- Restaurants, hotels, laundries, car washes
- Typically up to 25 or 50 gpm
- Larger tanks accommodate deeper resin beds
- Throughput capacity important
- Modest hardness leakage acceptable

Defining the System by Application

Industrial/Municipal

- Large factories, boiler water treatment, power
- High flow rates, continuous operation
- Low hardness leakage requirements
- Most tanks custom built

Practical Limits for Sizing

Flow Limitations	Bed Limitations	Inlet Contaminants (limits for best life)
1 to 10 GPM/cu. ft. 2 to 4 preferred	2 to 8 ft bed depth 4 to 6 preferred	0.3 ppm of free chlorine 0.0 preferred
2 to 20 GPM/sq. ft. 8 to 12 preferred	Max 25 psi loss across resin bed (<10 preferred)	1.0 ppm of turbidity 0.0 preferred
		1.0 ppm of iron Compensate for >1 ppm

Exhaustion time = 2 hours minimum (over 4 hours preferred)

Process Design

Basic Steps

- Calculate hardness load
- Determine capacity & leakage
- Set one variable - calculate the other
    - Choose resin volume, calculate throughput
    - Choose throughput, calculate resin volume
- Verify other sizing parameters are within limits

Sizing Example

Inlet Conditions

Flow: 100 gpm average flow

Hardness: 10 grains per gallon

Equipment:

- 2 x 100% capacity softeners specified
- 25 cubic feet of resin selected

Resin capacity: 22 kilograins per cubic foot (at 6 lbs/cu.ft. salt dose)

Sizing Example

Calculations

Throughput Capacity

25 cu ft x 22 kgrns/cu ft / 10 grains hardness in feed = 55,000 gallons per vessel

Run Length

55,000 gallons / 100 gpm = 550 minutes (9 hours)

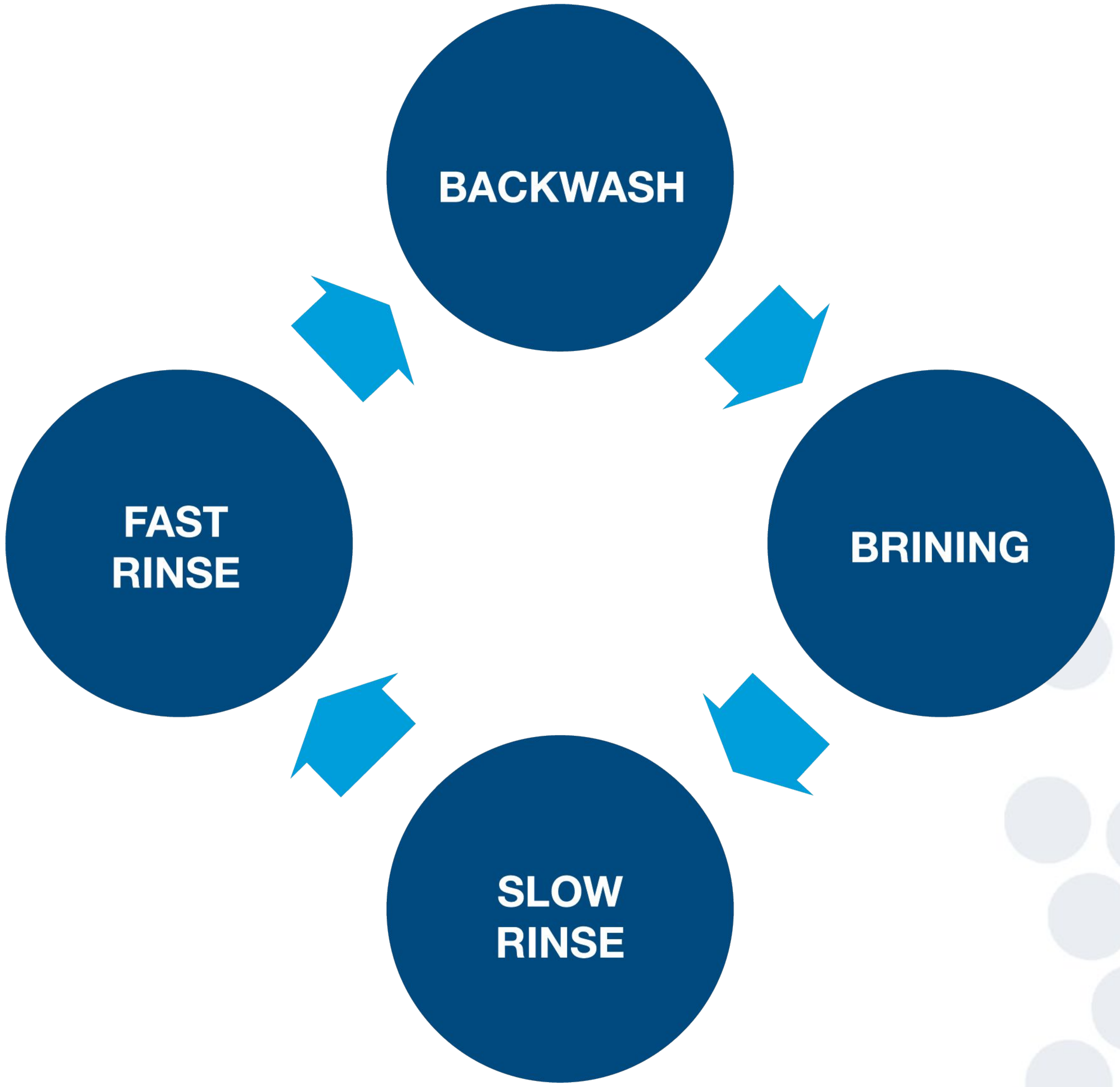
Vessel Size

25 cu ft / 4 ft deep resin bed = 6.25 sq ft tank area needed

36" diameter tank has 7 sq ft making the bed depth 3.5 ft

Final size 36 inch diameter x 72 inch tank

Four Steps of Softener Regeneration



Regeneration Procedure

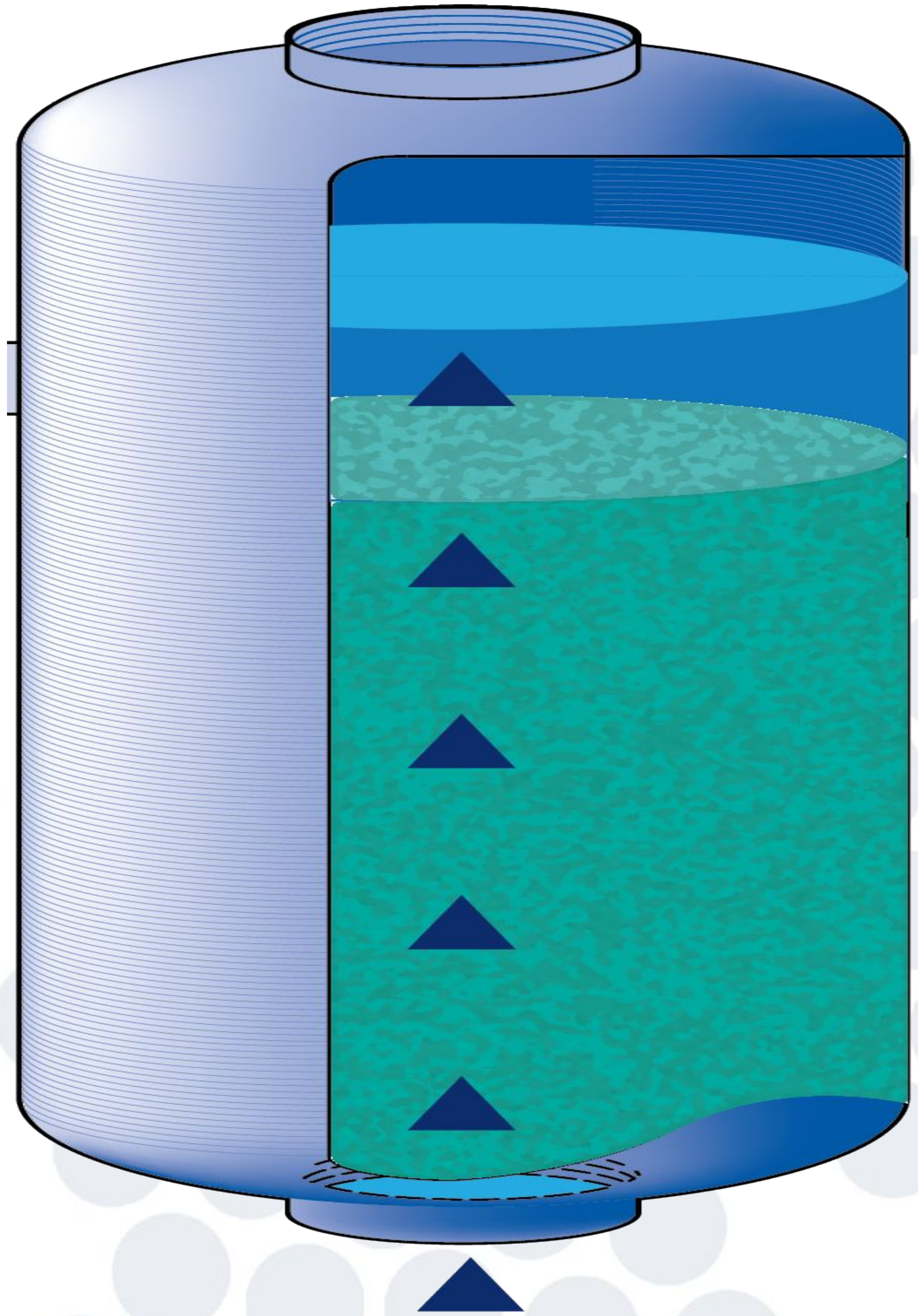
Step 1: Backwash

Flow Rate

- Expand bed a minimum of 25% at max temperature
- Expansion less than freeboard at lowest temperature
- Sufficient to remove broken beads, and dirt from the bed

Time

- 5 minutes minimum to fluff the bed with no turbidity present
- 10 minutes typical design
- 20 to 30 minutes when turbidity is present



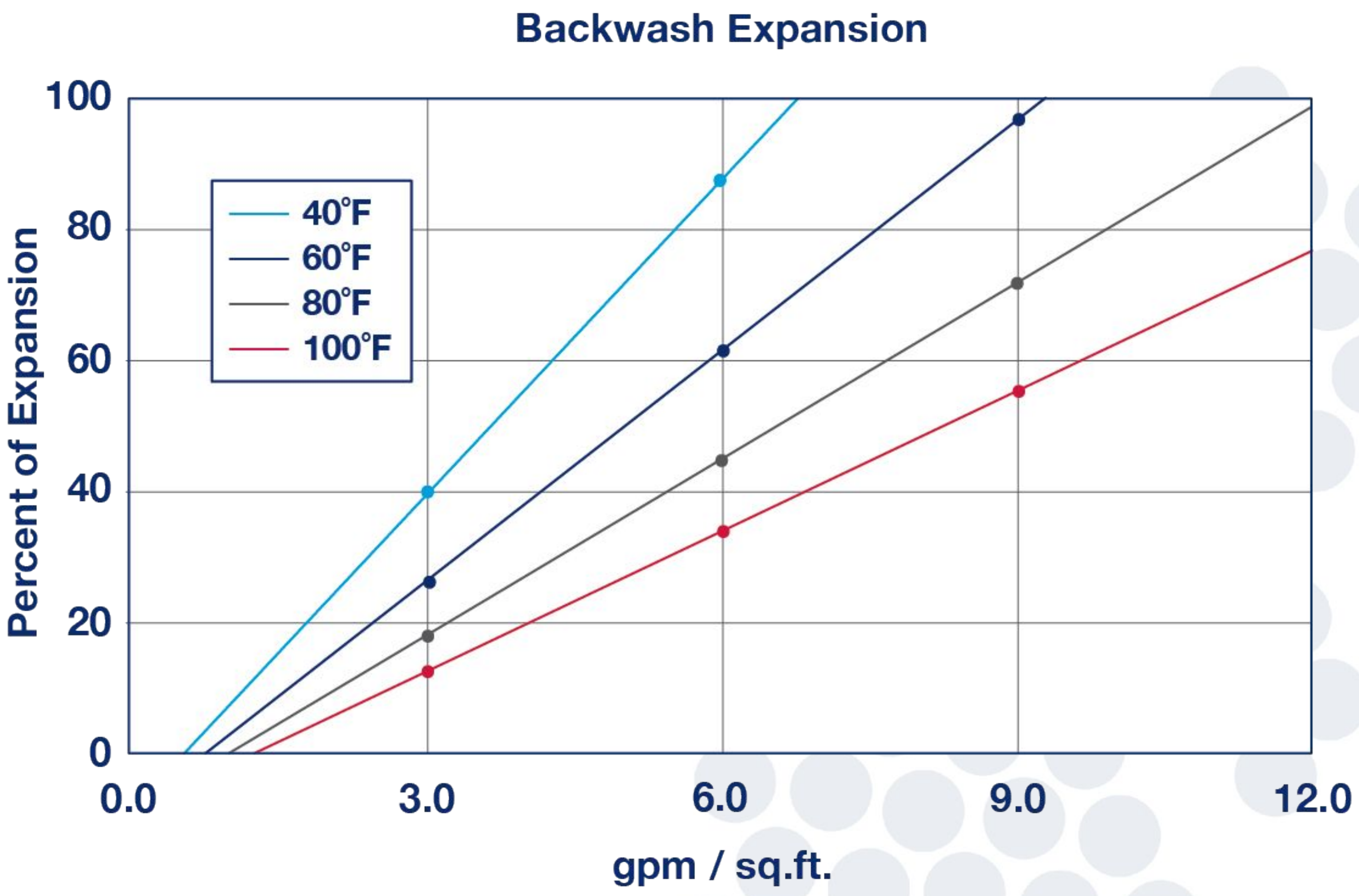
Backwash Water Temperature Effects

ResinTech CG8

A 36 inch diameter softener has 7 sq. ft. surface area

40% expansion at 60°F requires 4.5 gpm/sq. ft.

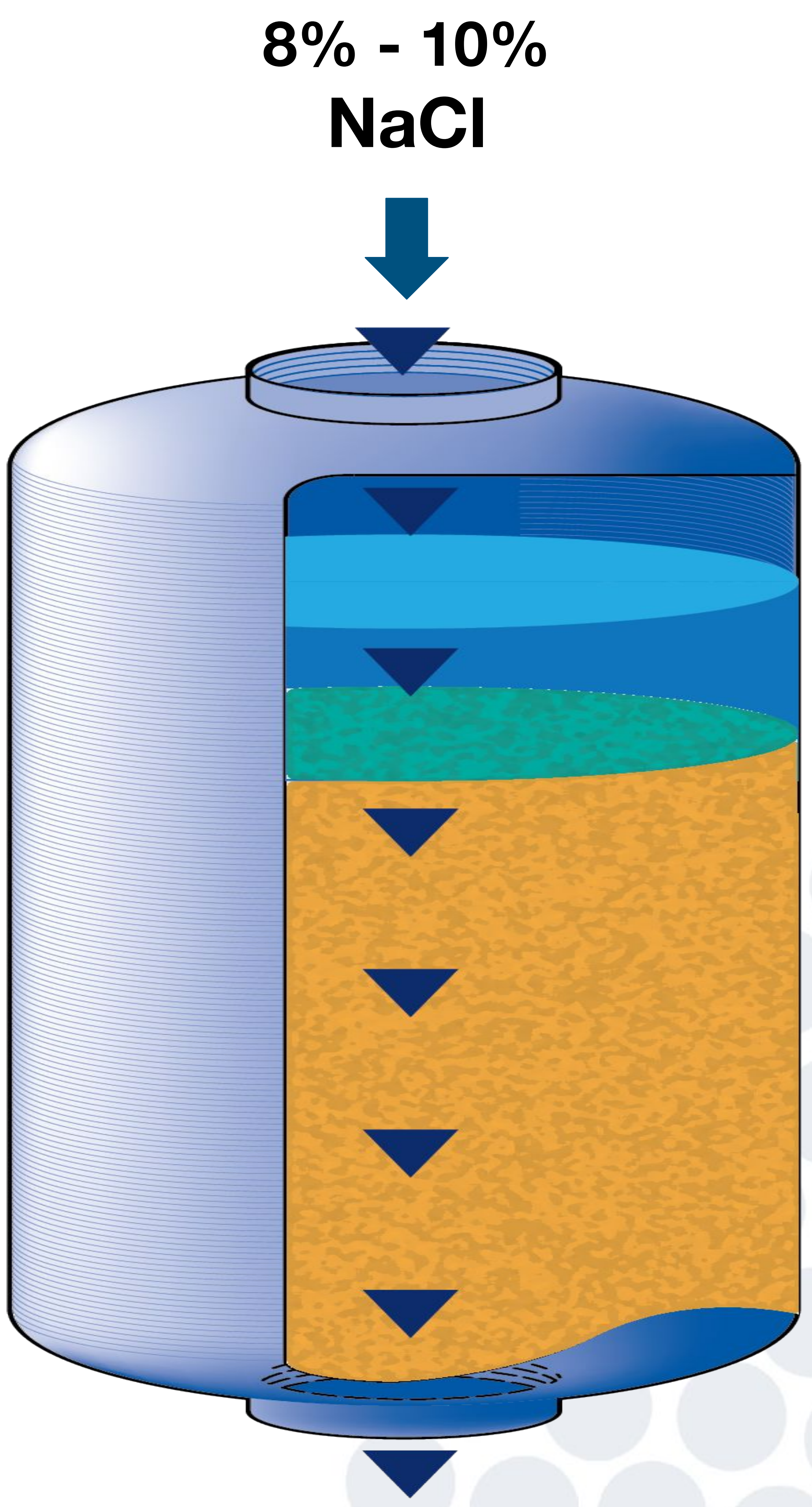
7 sq. ft. x 4.5 gpm/sq. ft. = 31.5 gpm backwash flow rate



Regeneration Procedure

Step 2: Chemical (Brine) Injection

- Restores exchange capacity
- 30 / 30 Rule:
  - Brine = 30% saturation
  - Contact time = 30 minutes
- Capacity vs. salt dose
- Leakage vs. salt dose



Brining Calculations

Volume of Resin: 25 cu. ft.
Dosage: 6 lb/cu. ft.

How much NaCl needed: 25 cu ft x 6 lb/cu ft = 150 lbs

How much saturated brine is needed?
150 lbs salt / 2.6 lbs/gal saturated brine = 57.7 gals saturated brine

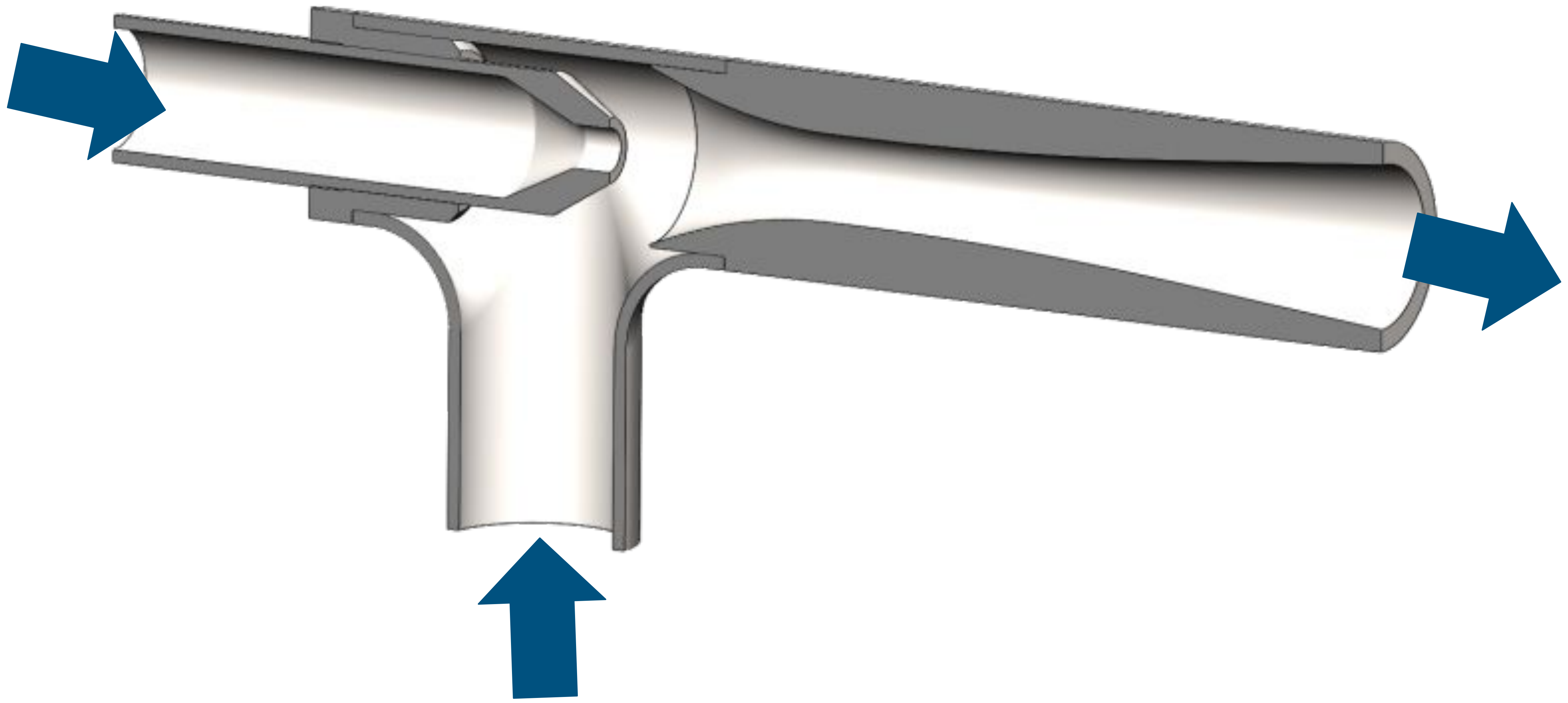
How much 10% brine is needed?
150 lbs salt / 0.9 lbs/gal in 10% brine = 167 gals dilute brine

How much water is needed?
167 gals dilute brine - 57.7 gals saturated brine = 109 gals dilution water

Brining Calculations

Dilution Water

109 gallons / 30 minutes
= 3.6 gpm



10% Dilute Brine

167 gals / 30 minutes
= 5.5 gpm

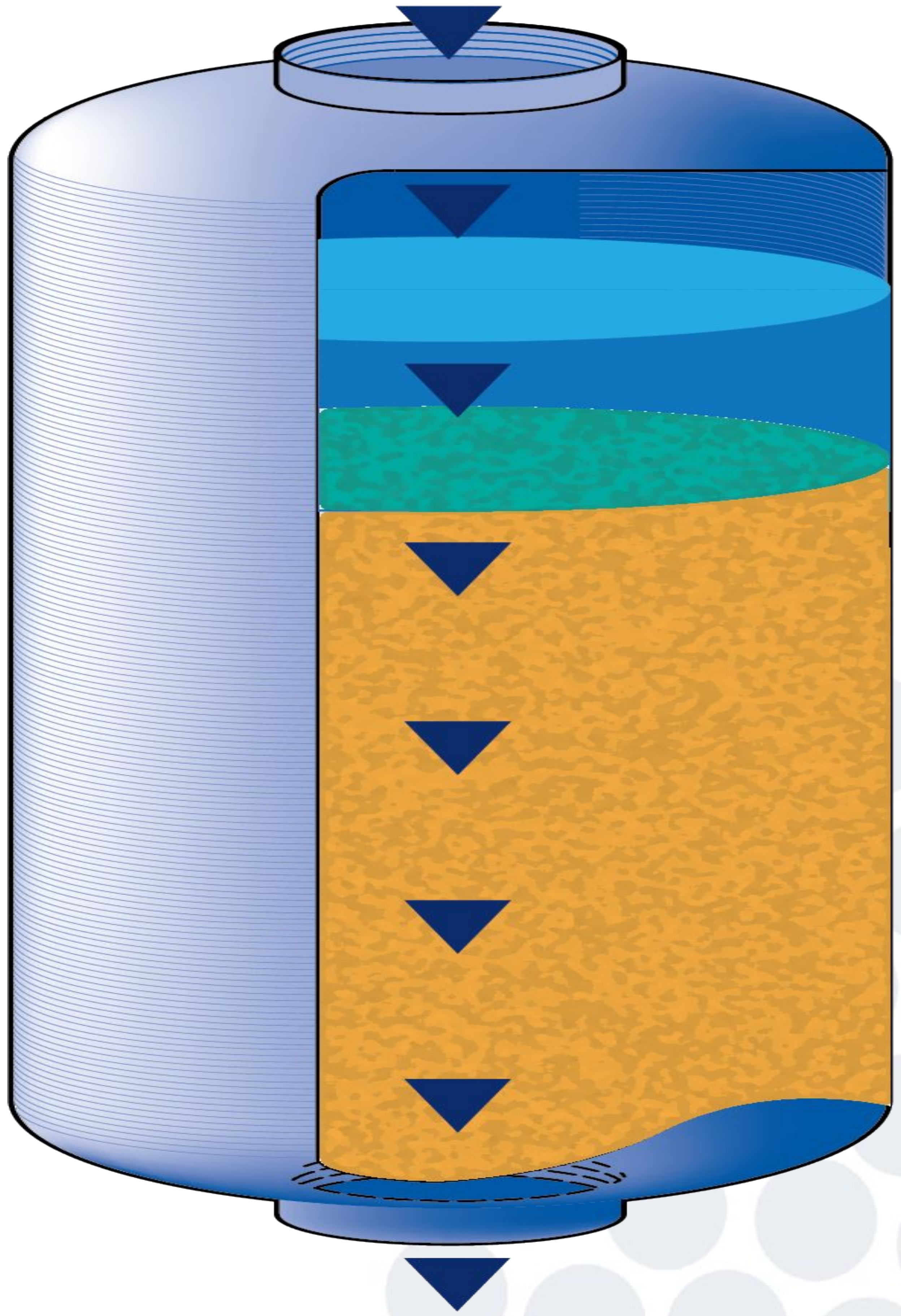
Saturated Brine

57.7 gallons / 30 minutes
= **1.9 gpm**

Regeneration Procedure

Step 3: Slow Rinse (Displacement)

- Displaces brine
- Time: 30 minutes
- Conserves salt



Regeneration Procedure

Step 4: Fast Rinse

Flow Rate

- Usually less than or equal to the service flow rate

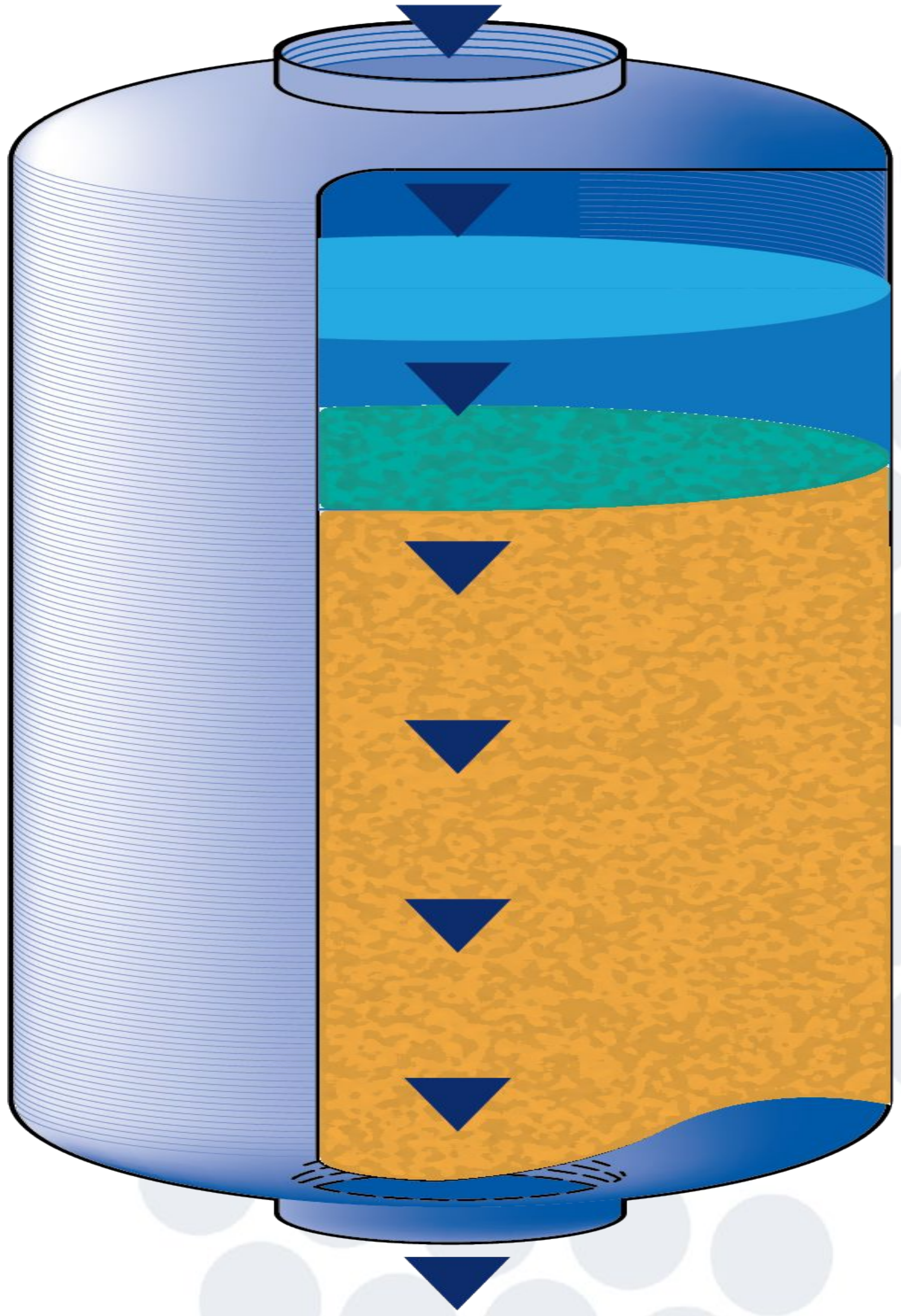
Volume

- ~40 gallons/cu.ft. to low hardness
- ~60 gallons/cu.ft. to no increase in chlorides
- Dirty resin/fouled resin rinse is always longer

Time

- Usually calculated from volume and flow

25 cu ft softener resin x 40 gallons/cu ft rinse = 1000 gallons rinse water

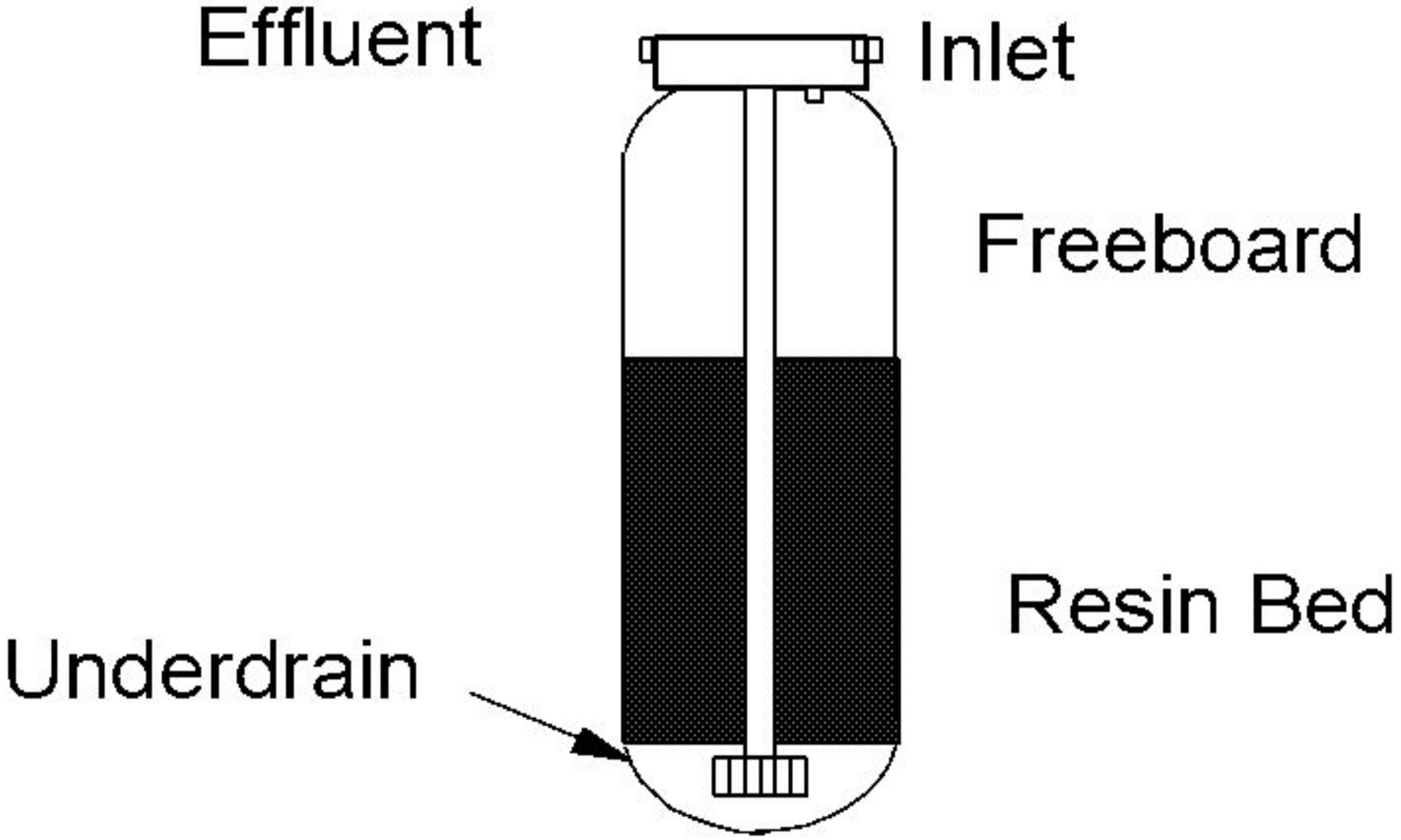


Regeneration Schedule

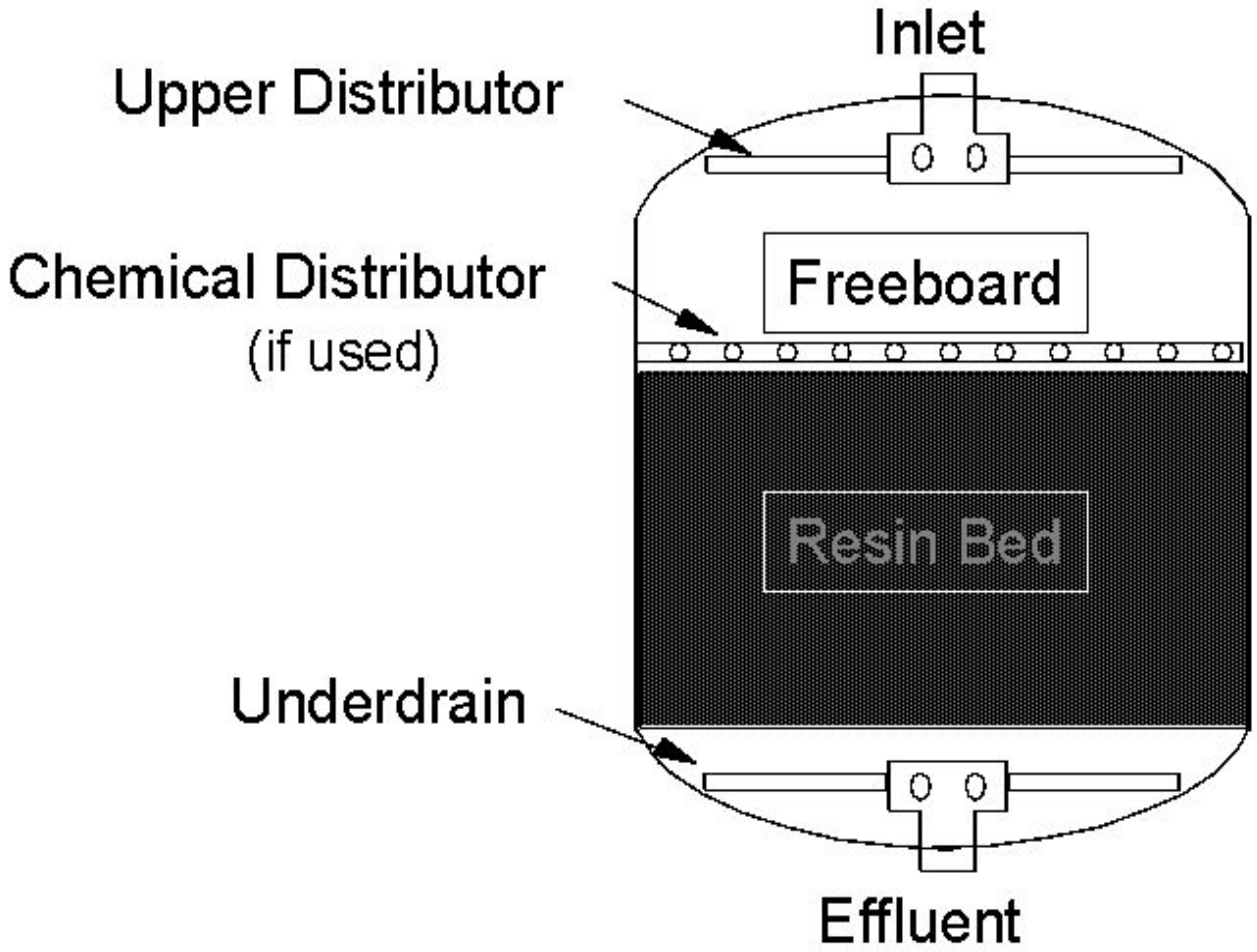
Completed Worksheet

Step No.	Description	Flow (gpm)	Time (min)	Wastewater (gals)
1	Backwash	31.5	10	315
2	Brine Inject	5.5	30	165
3	Slow Rinse	3.6	30	108
4	Fast Rinse	50	20	1,000
		TOTAL:	**90**	**1,588**

Household Softener



Co-current Regenerated Industrial Softener



Part 4: Softener Troubleshooting

SYMPTOM	CAUSE	ACTION
High Pressure Drop	Solids buildup	Inspect top of bed, perform vigorous backwash
	Resin degradation / breakdown	Test resin, replace if oxidized
Short Runs	Resin loss	Measure bed height, check internals, check backwash flow rate
	Low resin capacity	Test resin, replace if total capacity is low, or resin is oxidized
Short Runs/Hardness Leakage	Improper regeneration	Check brine tank for salt, perform elution study

Steps to Troubleshooting

- Check regeneration steps
- Recalculate throughput and leakage (based on CURRENT conditions)
- Comparison of the calculated results against actual field results
- Take a resin sample for analysis (check the resin level)
- Call ResinTech for advice

What Do We Need to Know?

- TDS (or conductivity) with min and max if variable
- pH and Temperature with min and max if variable
- Basic inorganic analysis of ions (Ca, Mg, Na, Cl, HCO_3, SO_4)
- Presence or absence of oxidants
- Level of suspended solids

Monitoring Performance

- Feedwater hardness, gpg
- Effluent hardness, ppm
- Differential pressure, psi
- Run length, gallons
- Amount of salt used per regeneration, pounds
- Rinse water, gallons

Common Mechanical Issues

- Resin loss
  - Backwash rates will change with temperature
- Brine system impairment
  - Injectors plugged, brine valve, salt tank bridging, etc.
- Control valve wear
  - Pistons, motors, etc.
- Don't overlook "simple"

Resin Fouling

Physical Fouling	Chemical Fouling	Biological fouling
• Suspended Solids • Iron	• Iron • Barium & other Heavy Metals • Aluminum • Organic Foulants (oils, polyelectrolytes, etc.)	• Mold • Algae • Bacteria

Inlet Water Chlorine Guidelines

Cl_2 Concentration	0-0.3 ppm	0.3-1 ppm	1+ ppm
Impact	Minimal effect on resin life	Some effects, reduced life	adverse effects, short life
Projected Resin Life	5-10 years	2-5 years	0-2 years

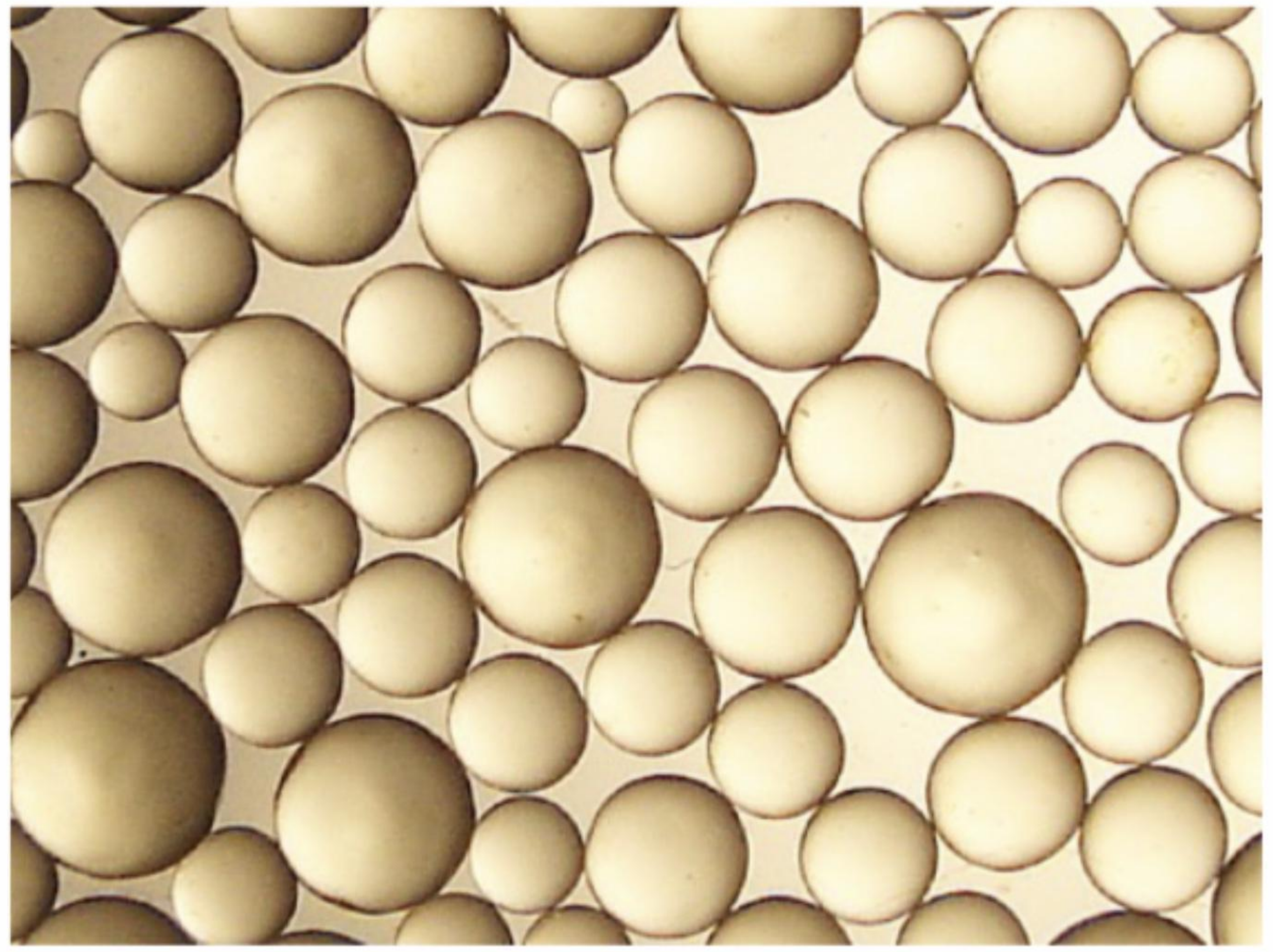


Image: New undamaged cation resin

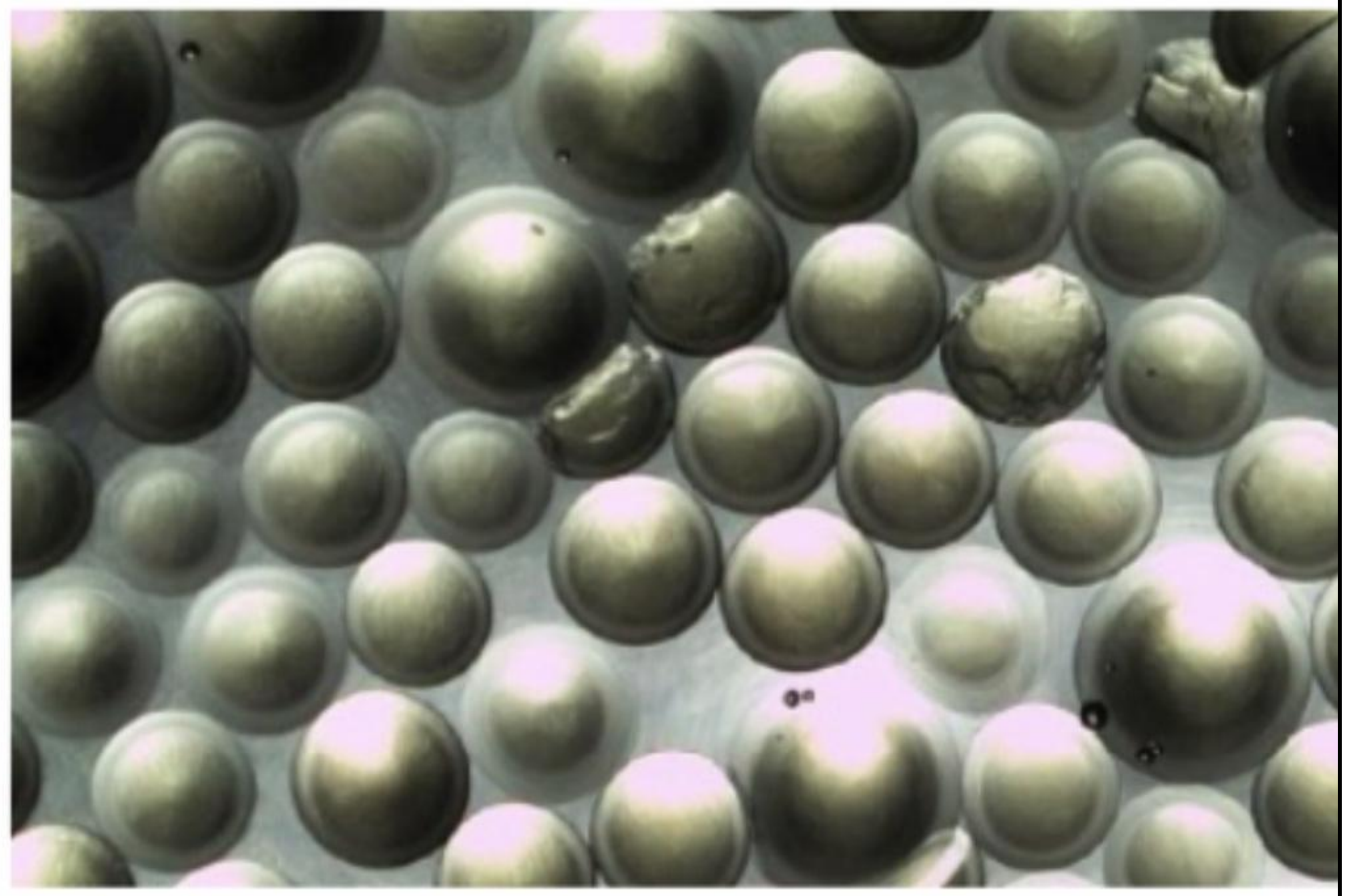


Image: Chlorine damaged cation

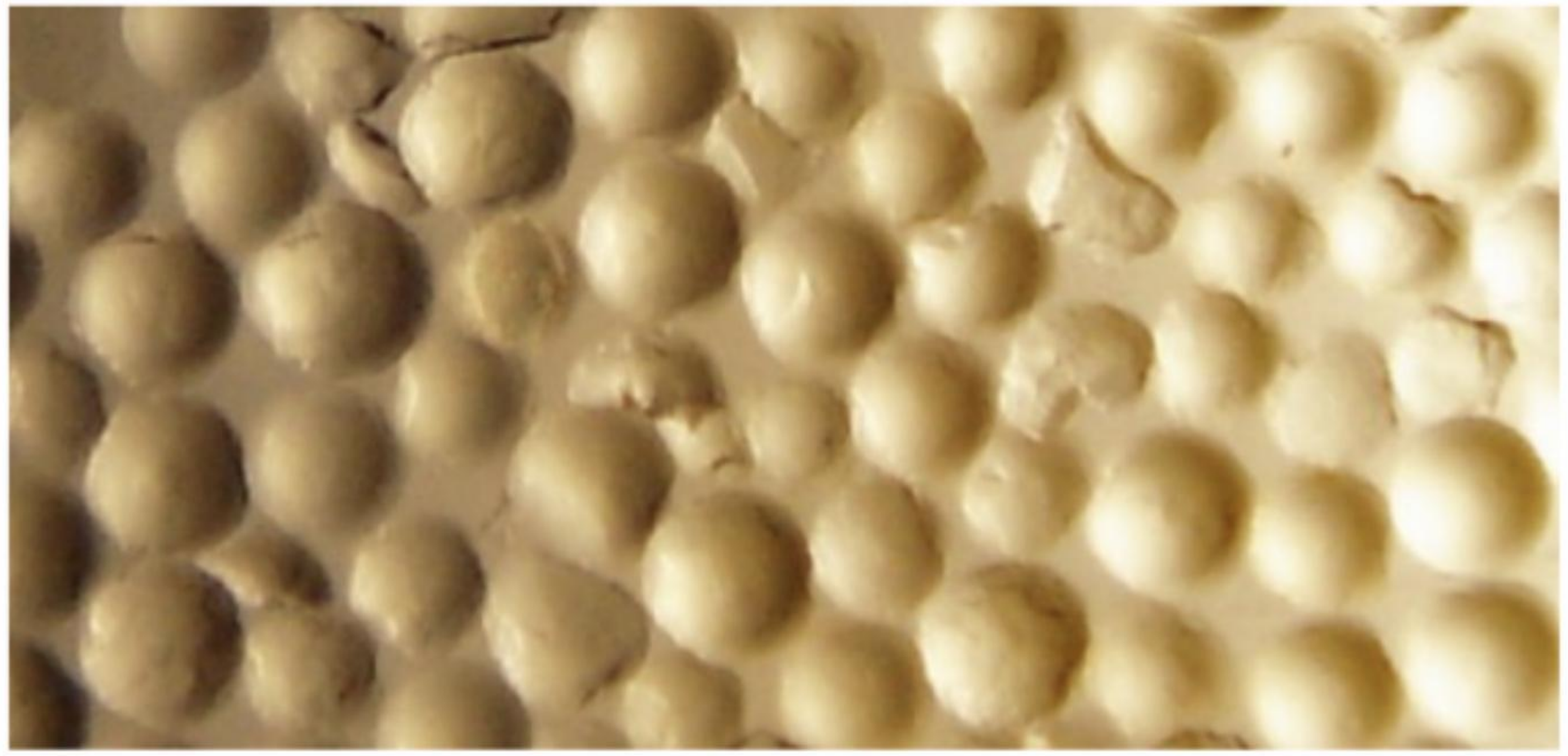


Image: Severely chlorine damaged cation resin

Is Resin Cleaning Practical?

Physical Fouling	Chemical Fouling	Biological fouling
Very Practical	Often practical but may have to be performed outside the softener tank	Very practical but may cause other types of damage to the resin

Resin Maintenance

Regular Use of Resin Cleaner/Brine Additive

- Improves Efficiency (surface contamination impedes IX)
- Prevents fouling
- Extends the life of the resin bed

Resin Sampling

- **Take <u>Core</u> Sample** (1 pint - 500 mL min.)
- **Label Properly**
  - Name, Address and Phone #
  - Sample ID
  - Kind of Resin / Model #
  - Application
  - Age
  - Regenerated or Exhausted
  - Reason for analysis

Resin Testing Results

Routine Tests

- Capacity
- Moisture Content
- Whole Bead Count
- Microphotograph

Optional Tests

- Site Analysis
- Effect of Cleaning
- Screen Analysis

Review

- **Keep it simple in terms of design**
- **Commercial / industrial softeners can be tricky to optimize** (leakage, throughput capacity, etc.). Consult your technical rep for assistance
- **Troubleshooting requires**:
  - original design specs
  - water analysis (design and current)
  - expected performance vs current conditions
  - resin sample
- **Ongoing maintenance / Resin treatment** (residential)

Questions?

THANK YOU

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ResinTech Inc.

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