Jim Schulman's Insanely Long Water FAQ

Provided by Jim Schulman | Originally Posted on alt.coffee

If you're only interested in the bottom line...

Use Volvic or Crystal Geyser Natural Alpine water in your home espresso machine. They have formulations that won't scale, but which still taste OK for coffee. On the other hand, if you want to take some pains and save some money, read on.

Content Note

The alt.coffee archives have answered almost all my coffee questions. However, the coverage on water problems seemed a little less than complete. So I'm adding this bit of research as a small repayment for all the help I've gotten here. It's too long to read in one sitting, so copy and peruse it at your leisure. Headings and subheadings are in block capitals; you can find what you need by scrolling through. There are several tables, so use a fixed pitch font.

This is not meant to be the authoritative word on water quality for coffee, I don't have nearly the expertise for that. I'm hoping to acquaint readers with enough information and sources so that we can argue water matters as proficiently as other coffee issues. There are bound to be mistakes in here, so I welcome all corrections. This FAQ covers the effect of minerals in natural waters on coffee taste and coffee makers. It has four sections. The long first one explains how to measure scale related water properties and how to estimate scaling rates in espresso machines based on these. The second looks at water treatments. The third taste tests espressos made with variously treated waters. The fourth puts together the conclusions of the first three and outlines water treatment and descaling options.

The FAQ does not discuss water impurities such as chlorine, organic materials, or heavy metals, since they shouldn't be in any drinking water, and since they're removed by all water bottlers, reputable types of water filtration, and municipal water boards. Municipal levels of chlorine are removed by charcoal filtration, letting the water stand two hours, or heating it. If your waterboard uses chloramines for disinfection, the water should be charcoal filtered prior to taste sensitive food use, since these do not dissipate on their own.

1. How to Measure Water Properties and Estimate Scaling Rates

A. Water Hardness Defined

Hardness is the term for the calcium or magnesium carbonate dissolved in water as Ca++, Mg++, and HCO_3- (bicarbonate) ions. There are two measures of water hardness, hardness and alkalinity. Hardness measures the amount of positive calcium and magnesium ions; alkalinity the negative bicarbonate ions. Both measures are usually given in calcium carbonate, i.e. scale, equivalent units (abbreviated as $CaCO_3$). This means when one unit of scale precipitates out of the water, hardness and alkalinity measured in $CaCO_3$ units go down by one unit each.

Alkalinity and hardness levels need not be the same, since the bicarbonates can be associated with potassium or sodium, and the calcium or magnesium with chlorides or sulphates. Usually, alkalinity is less than hardness, although some mineral waters and ion exchange softened waters rich in sodium or potassium may have higher levels of alkalinity.

Sometimes alkalinity is called "temporary" or "carbonate" hardness, the difference between hardness and alkalinity, "permanent hardness", and the hardness itself, "total" or "general" hardness. This usage is common among aquarium owners, but does not accurately convey how scaling works.

There are no health hazards associated with water hardness, so it is not subject to regulation. However, hard water causes scale, as well as the scumming and reduced lathering of soaps. Very soft waters, exposed to air or heat, become acidic and corrosive, and can harshen the taste of vegetables, tea, or coffee. So, several countries including the US, UK, Canada, and Germany have issued non-binding recommended hardness ranges. These are usually around 80 to 100mg/l hardness and 50 to 60 mg/l alkalinity, figures calculated to minimize the combined cost of scaling and corrosion in municipal piping and domestic hotwater systems. The levels required for taste, or for low maintenance steam boiler, spa, or aquarium operation, can be quite different.

Water boards call waters in the recommended range "neutral," those below the recommended range are called "moderately soft," below half the range, "very soft," above the range "moderately hard", and above twice the range "very hard." However, the exact ranges referred to by these names varies, and one should always get the exact water analysis.

B. Limescale Precipitation, pHs & the Langelier Index

Whether and how much scale precipitates depends on the water's alkalinity, hardness, temperature, and total dissolved solids. These factors together define a quantity called pH at saturation, or pHs. pHs indicates the pH level at which the measured calcium/magnesium bicarbonate level is at equilibrium saturation. If the pHs exceeds the water's actual pH, no scale will form. In fact, existing scales will tend to dissolve into the water. This is how the hardness gets there in the first place and why descalers are acids. If the pHs is less than the actual pH, lime will precipitate out of the water until the pH balance is restored.

The formula for pHs is as follows: The logs are base 10, T is temperature in centigrade, S is mg/l total dissolved solids, H is mg/l hardness, and A is mg/l alkalinity, both stated in $CaCO_3$ equivalent units.

$$pHs = 44.15 + \log(S)/10 - 13.12*\log(T + 273) - \log(H) - \log(A)$$

The quantity pH - pHs is called the Langelier Index or LI (sometimes called the Saturation Index or SI). A negative LI means no scaling, a positive one means scale will form. The LI formula is:

$$LI = pH + 13.12*\log(T + 273) + \log(H) + \log(A) - \log(S)/10 - 44.15$$

C. Water Analyses and Testing

Water authorities must publish their waters' composition and many put up the analyses on municipal websites. Bottled waters also will provide a complete water analysis on request and many bottlers state the composition of their water at this web site: http://www.bottledwaterweb.com/bott/ . Unfortunately, some don't, and some analyses are incomplete.

Mineral levels are stated in a number of different measurement units: milligrams per liter (mg/l) is standard. Parts per million (ppm), and the milligrams per decimeter cubed (mg/dM^3) used by MKS fanatics, are identical to mg/l. French degrees is mg/l divided by 10. Grains per US gallon are mg/l divided by 17.2. English degrees is mg/l divided by 14.3 (grains per Imperial gallon). German degrees (DH) or mmeq/l (the ueberscientific millimoles equivalent per liter) is mg/l divided by 17.9. Feel free to invent your own unit and add it here.

Finally, bottled waters mostly report their minerals as straight elemental mg/l or ppm rather than mg/l $CaCO_3$ equivalents. To get the alkalinity, multiply the bicarbonate by 0.82; to get hardness multiply the calcium by 2.5, the magnesium by 4.2, and add the two. If the water is fizzy, and bicarbonate level isn't stated; the alkalinity will equal the hardness after the water goes flat.

For do it yourself water testing, there are water test kits. The most accurate are to be found in aquarium supply stores, and require counting the number of drops of reagent to get a color change in the water sample. The color change happens when the sample reaches a preset pH level, the number of drops it takes measures the amount of buffering minerals present. They are sometimes called "titration to endpoint" tests.

The best buy I've found of this type are made by Aquarium Pharmaceuticals. Each one has about a fifty to a hundred hardness and alkalinity test per $6 kit (exact number depends on how hard the tested water is), and they have a complete line of other tests. They're available at PetSmart.

Editors note: It appears that PetSmart no longer carries this particular Aquarium Pharmaceuticals product, but googling "Aquarium Pharmaceuticals Freshwater GH & KH Test Kit" produces dozens of hits. Here's a detailed data sheet on the kit.

The tests use a simplified (no separate color changing dye needed) titration to endpoint system, and each drop measures one DH, or 17.9 mg/l, a resolution eminently satisfactory for coffee water testing. Moreover, the tests' resolution can be adjusted by using different water volumes. Doing these tests are cumbersome, since the test tube has to be stoppered and shaken after each drop of reagent is added.

Paper test strips are much easier; all the tests are on one strip, which is dipped into the water and compared to a color chart. They work similarly to the pH color strips one finds in high school chemistry labs. Unfortunately, the only one I found with the correct resolution didn't work (3 separate lots, none worked), so avoid test strips from Continental Hydrodyne Systems. The strips made by Aquacheck and Jungle Labs work well, but the steps are too coarse. Basically, these tests will get you no better than an estimate within 50 mg/l hardness or alkalinity. That's OK for spot checks, but not accurate enough for a fine tuned water treatment.

D. More on Alkalinity and Simplified Calculations

There are two items that need to be noted prior to doing calculations from published or test data. Most tests measure hardness and alkalinity. They do not measure total dissolved solids (this requires a conductivity test). But, since calcium, magnesium, and carbonates form the preponderance of dissolved solids in most natural drinking water, and since total dissolved solids plays only a small role in the calculations, the higher of the hardness or alkalinity measures (in $CaCO_3$ equivalent units) can serve as the total dissolved solids measure with only a minimal loss of accuracy (The LI will come out about 0.1 to 0.2 too high for water with lots of other minerals).

Second, acidity in natural water comes from dissolved CO_2 (fizz), which can vary quickly. A recent improvement on the Langelier index, called the Puckorius index, replaces the water's current pH with its equilibrium pH (pHeq), which derives from the alkalinity value. When water is exposed to air or heated, this works better as a long term pH estimate than any current pH reading. The formula is:

$$pHeq = 1.465*\log(A) + 4.54$$

The following table shows the alkalinity value that is equivalent to the medium pH levels in drinking water:

Equilibrium Water pH vs Bicarbonate Alkalinity in mg/L $CaCo_3$

pHeq	6.0	6.2	6.4	6.6	6.8	7.0	7.2	7.4	7.6	7.8	8.0
Alkalinity	10	14	19	26	35	48	65	90	123	168	230

By using these facts, one gets the following simplified, state of the art, Langelier index formula (LI*) that requires only temperature (T), hardness (H), and alkalinity (A):

$$LI^* = 13.12*\log(T+273) + \log(H) + 2.465*\log(A) - \log(\max(A,H))/10 - 39.61$$

Note that alkalinity has about 2½ times the effect on the LI as hardness, since changes to it effects both the water pH and the calcium carbonate saturation. Regrettably, most water information is misleading on this, since only hardness values are discussed.

E. Calculating Acceptable Hardness at Various Temperatures

As one can see from the LI formula, rising temperature raises the LI and the scaling potential. So it's useful to determine the maximum hardness and alkalinity levels that don't cause scaling for a given operating temperature. This requires solution of the following rewritten LI* equation:

$$\text{Max Hardness Allowed} = A*\log\{44.01 - 14.58*\log(T+273) - 2.739*\log(A)\}$$

or at higher alkalinities:

$$\text{Max Hardness Allowed} = A*\log\{39.61 - 13.12*\log(T+273) - 2.365*\log(A)\}$$

The following table gives some results for espresso boiler temperatures (115C - 130C) and coffee brewing temperatures (90C - 95C):

Maximum Non-Scaling Hardness by Temperature and Alkalinity

		Alkalinity											
°C	**Bar**	**33**	**37**	**40**	**43**	**47**	**50**	**53**	**57**	**60**	**63**	**67**	**70**
90	**--**	342	250	202	166	130	110	93	77	67	59	51	46
95	**--**	280	205	166	136	106	90	77	63	55	49	42	38
115	**0.67**	130	95	77	63	49	42	37	31	27	24	21	19
120	**1.00**	108	79	63	52	41	36	31	26	23	21	18	16
125	**1.33**	89	65	53	43	35	30	26	22	20	18	15	14
130	**1.67**	75	55	44	37	30	26	22	19	17	15	13	12

The Bar column gives the approximate boiler pressure that equates to the stated temperature.

This table amplifies the standard recommendations of 90mg/l hardness at brewing temperature and 50mg/l at boiler temperature. A slightly better rule of thumb, whenever the hardness and alkalinity are roughly at the same magnitude, is to add the two together: then coffee temperature water should not exceed 130 total, boiler water 80 total.

F. Estimating Scale Deposition Rates

When calcium/magnesium carbonate precipitates out as scale, it lowers the alkalinity and hardness measures by equal amounts (in the $CaCO_3$ equivalent units being used) until the LI drops to zero. At this point, scaling stops until more hard water is introduced.

The calculation doesn't have a closed form solution. If you have a programming language, write an iterative subroutine to solve this equation for x, the milligram amount of scale per liter throughput, for any H, A, & T you want:

$$0.9*\log(H - x) + 2.465*\log(A - x) = 39.61 - 13.12*\log(T + 273)$$

or

$$\log(H - x) + 2.365*\log(A - x) = 39.61 - 13.12*\log(T + 273)$$

Barring that, I've included two scaling tables:

Milligrams Scale at 95°C Per Liter Throughput

	Alkalinity											
Hardness	**25**	**50**	**75**	**100**	**125**	**150**	**175**	**200**	**225**	**250**	**275**	**300**
25	0	0	0	6	13	17	20	21	22	23	24	24
50	0	0	8	22	31	38	42	45	46	47	48	49
75	0	0	17	33	47	56	63	67	70	71	72	73
100	0	2	23	42	58	72	81	88	92	95	96	97
125	0	6	27	48	67	83	97	106	113	117	120	121
150	0	8	31	52	73	92	108	122	131	138	142	145
175	0	10	33	56	77	98	117	133	147	156	163	167
200	0	12	35	58	81	102	123	142	158	172	181	188
225	0	14	37	60	83	106	127	148	167	183	197	206
250	0	15	39	62	85	108	131	152	173	192	208	222
275	0	17	40	64	87	110	133	156	177	198	217	233
300	0	18	42	65	89	112	135	158	181	202	223	242
325	0	19	43	67	90	114	137	160	183	206	227	248
350	0	19	44	68	92	115	139	162	185	208	231	252
375	0	20	44	69	93	117	140	164	187	210	233	256
400	0	21	45	69	94	118	142	165	189	212	235	258
425	0	22	46	70	94	119	143	167	190	214	237	260
450	0	22	47	71	95	119	144	168	192	215	239	262
475	0	23	47	72	96	120	144	169	193	217	240	264
500	0	23	48	72	97	121	145	169	194	218	242	265

Milligrams Scale at 125°C Per Liter Throughput

							Alkalinity					
Hardness	**25**	**50**	**75**	**100**	**125**	**150**	**175**	**200**	**225**	**250**	**275**	**300**
25	0	0	10	17	20	22	23	24	24	25	25	25
50	0	7	23	35	42	45	47	48	49	49	50	50
75	0	13	32	48	60	67	70	72	73	74	74	75
100	0	17	38	57	73	85	92	95	97	98	99	99
125	0	19	42	63	82	98	110	117	120	122	123	124
150	0	22	44	67	88	107	123	135	142	145	147	148
175	0	23	47	69	92	113	132	148	160	167	170	172
200	1	25	48	72	94	117	138	157	173	185	192	195
225	2	26	50	73	97	119	142	163	182	198	210	217
250	3	27	51	75	98	122	144	167	188	207	223	235
275	4	28	52	76	100	123	147	169	192	213	232	248
300	4	29	53	77	101	125	148	172	194	217	238	257
325	5	29	54	78	102	126	150	173	197	219	242	263
350	5	30	54	79	103	127	151	175	198	222	244	267
375	6	30	55	79	104	128	152	176	200	223	247	269
400	6	31	55	80	104	129	152	177	201	225	248	272
425	7	31	56	80	105	129	154	178	202	226	250	273
450	7	32	56	81	105	130	154	179	203	227	251	275
475	7	32	57	81	106	130	155	179	204	228	252	276
500	8	32	57	82	106	131	155	180	204	229	253	277

Notes on the tables:

1. To obtain the composition of the water remaining in the boiler, subtract the amount of scale from both the hardness and alkalinity column.

2. Results for 120C and 130C differ from the 125C table by 1 or 2 mg/l scale less or more respectively. Similarly for the 90C and 100C tables to the 95C one.

3. The 125C table applies only to cases when liquid water is being extracted from the boiler. When steam is extracted, all minerals are left behind. So, the entire lower value of the hardness or alkalinity deposits as scale if the boiler water is fully saturated with an LI of 0 or higher.

4. If boiler water is not saturated, the hardness and alkalinity values rise in proportion to the proportion of steam extracted tempered by the values of the feedwater replacing the lost steam. Barring any water extraction, the hardness levels will eventually climb to saturation. Therefore, even if the feedwater is below the boiler's saturation point, scaling may still occur if a high proportion of use is as steam.

Actual mineral concentrations in the boiler, if saturation isn't reached, depend on the ratio of steam to water extraction and is as follows:

Boiler Concentration = Feedwater Concentration/(1 - Steam Ratio)

No scaling occurs only if the boiler concentrations of alkalinity and hardness yield a negative LI. Therefore boilers used only or primarily for steaming must be flushed (blown down) regularly, with the schedule depending on the mineral concentration of the feedwater and the volume of steam use. Water treatments must be chosen with these factors in mind.

G. Estimating Scaling Rates in Espresso Machines

When a given lot of water has dropped enough scale to lower its LI to zero, it doesn't scale any more. So scaling is not dependent on how long an espresso machine is on or how much water it holds; it depends solely on how much water goes through it (this is a slightly conservative approximation, since the water may not completely descale if it's at maximum temperature for only a short time).

So the scaling tables given above can be used to estimate the amount of scale that your espresso machine is accumulating. The only thing required is an estimate of the number of liters of water heated to coffee and steaming temperatures going through your machine. Multiply this figure with the amount of scale given for your water's hardness and alkalinity, and you have the scale estimate.

In order to aid in this calculation, I have included a water volume table for different types of drinks, as well as some examples.

Liters per Month for One Drink per Day

Drink	Espr+0	Espr+2	Espr+4	Espr+6	1CapSteam	Americano
Liters	1.80	3.60	5.40	7.20	0.61	3.60

Some explanations

The espresso + 2,4,6 refers to running ounces of water prior to pulling the shot: on single boiler machines, to temperature surf; on HX machines, to cool down the water or temper the head after idle time. Use the figures appropriate to your practice. Commercial estimates require knowing how often the baristas run water.

Sometimes espresso volumes go against the 125C table. On a home machine cappa, the entire amount used for the espresso is replaced in the boiler, then heated to steam temperature, thus the usage creates 125C level scaling. If the boiler is never set to steam, the 95C table should be used. On an HX machine, HX water used after idling is at 125C; whereas "follow on" shots during high traffic are at 95C.

Americanos pulled from water temp home boilers go to the 95C table, those pulled directly from a steam boiler go to the 125C table. Those made via a 2nd HX system go to the 125C table if there's been idle time, otherwise to the 95C table. The Americano amount given is additional to the espresso total.

If water scales at all at boiler temperature, the cappa steaming volumes should be calculated at the lower of the water's hardness or alkalinity figure, rather than the 125C figure, since all minerals from the steamed water remain behind and scale out.

Some Examples

1. A Silvia running 175 hardness, 125 alkalinity water is used for 1 cappa, 1 americano, and 3 espressos daily. The temperature surf is 4 ounces.

The cappa shot is on the 125C table:	5.40	×	92	÷	1000	=	0.50
The three espressos on the 95C one:	16.2	×	77	÷	1000	=	1.25
The americano also on the 95C one:	3.60	×	77	÷	1000	=	0.28
The steam use drops 125 mg:	0.61	×	125	÷	1000	=	0.08

Total = 2.11 grams per month

2. A coffee shop dual heat exchanger machine running 100 hardness, 50 alkalinity water (perfect coffee water) is used for 20 espressos, 400 milk drinks, and 80 Americanos per day. About 100 drinks are made after idle times and require 4 ounce HX flushes, the rest are "follow on" shots without HX flushes. All the Americanos are made with pauses in between.

Boiler scale:	400 drinks	×	0.61 liters	×	50 mg	=	12.2 grams/month
Water HX scale:	80 drinks	×	3.60 liters	×	17 mg	=	4.9 grams/month
EsprHX scale:	100 idlers	×	5.40 liters	×	17 mg	=	9.2 grams/month
Espr HX scale:	400 follows	×	1.80 liters	×	2 mg	=	1.4 grams/month

H. Corrosion and Water Hardness

When corrosion is a danger in hot water systems, as with Gaggia home machine boilers, it is accelerated by acidic water and heat, and retarded by a layering of limescale. Thus, the standard recommendation is using water with an alkalinity high enough to ensure the water never becomes acidic, i.e. 48 mg/l or higher, and enough hardness to keep the Langelier Index above -0.5. At room temperature, an LI of greater than -0.5 translates to an alkalinity above 75 mg/l and a hardness above 150 mg/l.

The LI recommendation is somewhat contested for two reasons. First, limescale layers only protect when they form a complete coating. Second, in heated systems, the LI stays high when the system is hot, and only drops to critical levels when the water is cold. Since both lime formation and corrosion are slowed in cold water, the benefit of a high cold water LI isn't all that great. However, keeping the alkalinity above 48 mg/l is seen as a must by all experts.

The value of high alkalinity for corrosion protection, along with the lesser value of scale, leads to a surprising conclusion: hardness can worsen corrosion in hot water systems. When the heated water drops scale, it loses alkalinity as well and can become corrosive. This observation accounts for the frequent occurrence of both scale and corrosion in Gaggia boilers. But if the bicarbonate alkalinity is mainly coupled to sodium and potassium, it won't scale, and will remain in the water even when heated. This means that water with higher bicarbonate alkalinity and lower calcium/magnesium hardness is best for protecting hot water systems from corrosion.

2. Water Treatments

If the local tap water is unsuitable, and bottled waters too expensive, a third alternative is to treat the water yourself. The following options are available.

A. Charcoal Filtering

Charcoal removes chlorines, odors, colors, and cloudiness, but does not affect the water's mineral content. It is an excellent idea for poor quality water, when chlorinated water is drunk directly without heating it or letting it stand, or when chloramine instead of free chlorine is used for disinfection. Charcoal filters are fairly low maintenance, needing only occasional cartridge swaps. Brita, Pur and Culligan cartridges always include charcoal filters. Most installed treatment systems also have one, as well as one or more of the following items.

B. Mineral Introduction

When water is deficient in some key mineral for its intended purpose, minerals are added by running it through a bed of salts. Usually these beds contain sodium, calcium or magnesium bicarbonates or sulphates; but the exact composition varies by purpose. High quality water treatment systems have mineral cartridges downstream of reverse osmosis units.

C. Distillation and Reverse Osmosis

Distillation removes all water impurities, good or bad. Nowadays, one can buy 1 liter per hour countertop distillers, but otherwise the much more efficient reverse osmosis process is used. In reverse osmosis, some water is forced through a membrane impermeable to minerals which are washed away by the proportion of water not passing the membrane. RO should produce virtually pure water (below 1 mg/l total solids); however, mineral removal is compromised when the amount of waste water is reduced. For instance, supermarket RO vendomats in very hard water areas may put out as much as 50 mg/l hardness and alkalinity levels. Home reverse osmosis systems are generally self-cleaning, but need to be installed and set up by specialists. They are more expensive to buy and operate than ion exchange softeners (see below).

D. Ion Exchange Softening

Ion exchange runs the water through a polystyrene resin or zeolite bed saturated with sodium and/or potassium chloride. The resin bed is usually cationic, that is, formulated so that highly solvent univalent cations (sodium or potassium) replace the less solvent multivalent ones in the water (calcium, magnesium, iron, lead and other heavy metals). This version reduces hardness without reducing alkalinity. Alternatively, an anion resin will replace the bivalent bicarbonates with more soluble univalent hydroxide, chloride or sulphate ions. This version reduces alkalinity without reducing hardness or heavy metals. Dual systems that produce completely softened water are also available.

The amounts of sodium or potassium introduced by cation softeners are below the taste threshold, and are not a health factor at coffee consumption levels. For each 100 mg/l $CaCO_3$ hardness removed, 46 mg/l sodium or 78 mg/l potassium are added. However, sodium restricted heart patients are sometimes advised not to use sodium exchangers for drinking water. In no case should cation ion exchange water be used to water plants, since sodium and potassium accumulate in soil.

Plumbed in, self recharging ion exchange systems generally reduce hardness (and/or alkalinity) to below 20 mg/l. They are cheaper than RO systems of the same capacity and require less maintenance. To get the same performance from pourover espresso machine hose units, the filters have to be recharged regularly.

Both Brita and Pur jug filters have ion exchangers designed to eliminate heavy metals, but which also remove some hardness as a side effect. They are of a non-rechargeable variety that add hydrogen, rather than sodium, to the water. The water emerges slightly and temporarily acidic. The Claris filters in Jura/Capresso machines apparently also work this way. They do not completely remove hardness, rather reduce it by 33% to 67%, depending on the age of the filter. Neither company's water tap filters use ion exchange, instead relying on a catalyst layer to remove heavy metals. They have no effect on hardness.

It proved impossible to get accurate information on performance of either the Brita or the (generic?) hose end softener sold with Silvias. So I decided to do my own testing. Here are the results:

Brita Jug Filter

I tested the filter new, and after 3 weeks, or 75 liters use (about half the recommended cartridge life) on 150mg/l hardness, 100 mg/l alkalinity water. As expected, the filter left the alkalinity unaffected. Only about 2/3 of the hardness was removed when the filter was a few days old, and its performance dropped to 1/3 removal after three weeks. This probably is due to it being designed to remove heavy metals, rather than calcium. The NSF's refusal to allow Brita to advertise in the U.S. as a water softener is therefore not just bureaucratic gobbledygook, but justified by the facts. I have not tested the Pur jug filter or the Claris system; the identical design principal probably results in similar performance.

Rancillio Silvia Softener

This is the small softener sold along with the Silvia that fits on the intake hose end. The softeners sold with other machines look identical, so this may be a generic product. I was told to recharge mine weekly with a few tablespoons of pure salt in a highball glass. The test result is based on this procedure. This softener also does not completely eliminate hardness. In my case, it reduces hardness from 150 mg/l to about 50 mg/l. The performance is about equal to a new Brita jug filter. Weekly recharging keeps it at this level. At this level of softening, my water still generates scale, but at about half the rate of unsoftened water. The softening creates close to zero LI water at coffee brewing temperatures, albeit with higher alkalinity than hardness. The combination of a new Brita and hose end did reduce the water to a 20 mg/l nonscaling level.

All in all, neither the Brita nor the hose end unit will produce boiler safe water either alone or in combination unless your tap water is already fairly soft.

It should be noted that the performance of ion exchange softeners is affected by temperature. In particular, their performance degenerates when the water is above 15C. Since the water in a pourover semicommercial machine is usually closer to 35C, this may have affected the test results.

E. Total or Combination Water Treatments

The above treatment options can be combined to get water with more or less custom mineral levels. The simplest and most common approach is to reintroduce proportion of charcoal filtered tap water downstream of the RO unit to raise hardness and alkalinity to a 30 mg/l range.
This is still boiler safe, but greatly improves coffee taste over straight RO water. It requires no more maintenance than a straight RO system. Some systems use custom replaceable mineral cartridges downstream of the RO unit.

Aquarium owners use more complex mineral bed systems to control each key mineral level independently. Such systems are extremely high maintenance, requiring frequent water testing and bed manipulation. Follow the aquarium links at the end to get more information.

F. Non-Mineral Adjusting Water Treatments

There are anti-scaling treatments available that do not rely on lowering hardness levels. However none can be recommended.

The first uses crystalline polyphosphate additives. These additives are FDA approved for drinking water, and some companies do sell them as espresso machine water treatments. They work because the polyphosphates form a crystal core to which the scale clings rather than depositing on metals. These particles remain suspended in the water. Barry says this treatment is worse for coffee taste than simple softening, and this makes sense. The limescale encrusted polyphosphate crystals will lodge in the grinds and interfere with the extraction. I have found one Austrian espresso machine dealer who sells a polyphosphate cake to be dropped into the tank and changed annually. I'd welcome any reports about their efficacy and effect on taste.

A second approach electrifies the water with a low powered, radio frequency alternating current. No authority I've found endorses this method except for the tongue in cheek Wessex water board, which comments that "some of our more cherished customers like it. " Perhaps they have proponents of Kirlian photography as customers, who, according to their web sites, think this also imbues water with a sort of life force.

Finally, some people on Kaffee-Netz keep their water mildly acidic using lemons or citric acid. If the water's pH is kept below about 6.3, this will work to eliminate scaling in moderately hard water. This is in essence a simple mineral bed treatment. It will stop scaling, but the effect on coffee taste may be worse than softened water. The required level is about 1/4 to 1/3 teaspoon of citric acid per liter.

G. Brands of Water Treatments

I regret that I could not find enough information, nor had the testing resources, to let me recommend or demur the many available brands of water treatment. Given what I've learned, I find the selling tactics of almost all that I've seen completely reprehensible, as they trade heavily on fear and ignorance (yes Virginia, you will die if you drink tap water). However, it could well be that some or all work as they should. I'd welcome reports by users of these units.

3. Water Hardness and Taste

A. Facts and Theories About the Best Coffee Water

The taste of straight water is quite subjective. Bottled waters mostly come in two kinds, alkaline ones with massive mineral levels just below brackish, and acidic ones with mineral levels just above RO flatness. Very few have the intermediate hardness levels found in most municipal waters. Moreover, the taste claims and taste test results of bottled waters bear no obvious relation to their chemical composition; although being as different as possible from the local tap water may be a factor. Fizzy waters with high bicarbonates like Perrier or San Pellegrino start out tangy acidic and become alkaline mellow as they fizz out, so they have the advantage of suiting any taste.

Fortunately, the effect of water on coffee is a different story. Taste testing by various authorities over the past twenty years has established a rough agreement that neutral pH water with 90 mg/l hardness is optimal for coffee taste.

There's one important thing to note here. It's almost impossible to brew coffee with neutral pH water that's too hard, since raising it to 95C will drop out the hardness in excess of 90mg/l to 100 mg/l as scale. Asking why this is so raises some new questions. Some water experts in Germany and Italy believe that the Langelier Index is behind the test results. According to their theory, a negative LI affects coffee extraction the same way acidic water would, tasting brighter and rougher than it should. Thus, the ideal coffee water has a neutral pH of 7, which means an alkalinity of about 50mg/l, and an LI of zero in the 90C - 95C temperature range, which means a hardness of about 90mg/l. Notice that this approach also makes alkalinity a factor in coffee taste.

Italian authorities, especially Segafredo, insist there is an additional criterion, that calcium hardness is preferable to magnesium for taste, whereas the SCAA and German authorities do not distinguish calcium from magnesium hardness. This could be an issue with the delivered drinking water in water coolers, which typically are RO water with added magnesium salts.

B. A Taste Test

These disputes call for a taste test. However, there's little point doing the tests with brewed coffee. First, limescale is a trivial problem in brewed coffee makers, so there's no reason to use soft water when brewing coffee. Second, in good espresso, crema, mouthfeel, and balance play a much larger role than in brewed coffee, so results from a brewed test may not apply to espresso. The drawback of an espresso test is that I can't do it side by side, since I need a few minutes to switch waters in the tank and let my tastebuds recover. I settled on tasting at fifteen minute intervals and relying on my notes and taste memory for comparisons. I believe if I can't distinguish the taste from different waters at this short an interval, water quality isn't a big deal. To keep myself undeluded, I blind tasted by shuffling the water bottles.

I used four different waters. The first was boiled hard water, at 100 hardness, 50 alkalinity. This is ideal for brewed coffee, and will be the water one gets out of an espresso temperature boiler whenever one runs anything harder through the machine. The second is straight RO water with less than 10 hardness and alkalinity. The third is RO water with charcoal filtered tap water added to get a 40 hardness, 25 alkalinity level. This approximates the composition of a competent water treatment for commercial espresso machines. The fourth is ion exchanged water with 100 alkalinity and less than 20 hardness, this approximates the composition of water when using an ion exchange hose end or cartridge type softener. The hardness and alkalinity figures are +/- 7.5 mg/l.

Espresso Taste Test

Water Hardness	RO	RO + Tap	IonEx	100/50
Crema	9	9	9	9
Body/Mouthfeel	4	7	8	9
Sweetness/Balance	3	8	9	10
Roast Flavors	6	9	8	9
Finish	3	7	8	9
Total	35	49	51	54

The RO water didn't really produce an espresso, but rather an unbalanced, overly bright shot of strong coffee with crema on top. It's identity was painfully obvious. The proper mineral level espresso was distinguished by a slight edge in the things I like in an espresso, rich oily mouthfeel and sweetness, but I was using my own blend which is formulated to really max these out at the expense of complex origin flavors (50% total of Robusta, Brazil, Java, and Uganda). Otherwise, the two boiler safe variations fared very well and were nigh indistinguishable.

C. Other Water Factors in Coffee Taste

There are several websites that insist good coffee water is fresh. Some go so far as to change the water in their tanks every few hours, lest the water gets too warm from the machine's heat and go stale. As justification they mention that fresh water has dissolved gasses, and stale water does not. Most municipal tap water has less then 5 mg/l dissolved oxygen, since it is foolishly allowed to go stale while sitting in purification ponds. Even if you attach an aquarium aerator to your water intake, the extra dissolved oxygen won't survive heating to brewing temperature (although really gassed up water may do some amusing things to your boiler). Needless to say, this is one of the more silly ideas I came across.

Dissolved chlorine and other gasses are also removed by standing and heating, so carbon filtering is not strictly necessary. The exception is when your municipal waterboard does its disinfection with chloramines. This is a fully soluble form of chlorine that remains in the water. The good news is that it isn't nearly as tasteable as regular chlorine. But it does have a taste; and it can and should be removed by carbon filtering in water for food or drink.

4. Water Treatment and Preventive Descaling for Espresso Machines

A. Scope

This section does not deal with what commercial espresso people understand by descaling, that is, disassembling the machine and removing large amounts of scale using picks and long, strong acid baths. It does deal with flushing home use machines relatively quickly with mild acids to dissolve small amounts (5 grams or less) of scale. Since the term "descaling" is also used for this procedure, and since this has caused some confusion in alt.coffee conversations between pros and amateurs, I'm going to call it "preventive descaling" instead.

First I'll describe how preventive descaling is done on various machines to give readers an idea of how much work is involved. Then I'll describe various water treatment options to get the coffee taste and preventive descaling frequency you want.

B. Preventive Descaling

Descaling Solution

Generally, a flush through descaler uses about .5 to .75 fluid ounces (1 to 1.5 tablespoons, or 8 to 12 grams) of citric or tartaric (grape) acid powder dissolved in 1 liter of water. This is a 2.25% to 3.5% solution, equivalent to 33% to 50% dilute lemon juice. Cleancaf and other coffee manufacturers' descalers use this formula. Theoretically, these amounts will dissolve about 12 to 18 grams of scale per liter, but that would require leaving the solution in for several days; in practice, it is used for an hour or two to dissolve up to 5 grams of scale.

The formula is mild enough to be harmless to espresso machine components, but it will come out of brass or copper machines with a slight greenish tinge. This comes from milligram levels of dissolved copper and is no cause for alarm.

Five pound bags of citric or tartaric acid cost about $10 at home brewers' or soapmakers' supply stores. This is roughly a 20 year supply

Descaling Intervals

Know the hardness of the water you're using, and how much you use the machine. Descale when accumulations are between 2.5 and 5 grams. More often is a waste of time, less often may result in scale build up. Check out section 1.7 for instructions on determining your set up's scaling rate.

Single Boiler Machines

For single boiler machines, preventive descaling is no problem, just follow the instructions given by the manufacturer. In general, this involves filling the boiler, letting the solution work for about ten minutes, and replacing it by running it out of the steam wand under pump pressure. This procedure is repeated three to five times, until about a liter of descaler is used up. Then the machine is flushed with water until any taste is gone.

Manufacturer's recommendations differ on whether the brewhead should be flushed or not. This is not surprising. The water's temperature drops and LI rises as it moves from the boiler to the head, so scale won't form there. In scaled machines however, fragments can move from the boiler into the head, fouling the gicleur valve. My guess is that with regular descaling, flushing the head is unnecessary but harmless.

I do not know if the dual boiler Techno can be descaled in this way, or if there is some procedure peculiar to it.

Heat Exchangers

HX machines have two things to descale, the boiler and the heat exchanger(s). Any descaling of a plumbed in machine will involve moving the water inlet pipe to a tank that can hold the solution.

Doing the heat exchanger is as easy as a single boiler machine. Just run descaler through it until it exits the brewhead (or HXed tap). Leave the descaler in for 5 to 10 minutes with the machine off (or 2 to 4 with it on), then run out a 3/4 cup worth, repeat six times until you've used up a liter of descaler. If the boiler refill comes on during this period, very little harm is done, since it will be adding only 20 ml or so to a liter or more of boiler water. Boiler flushes (see below) can be scheduled after an HX descaling to minimize this problem even further. However, only use citric or tartaric acid for HX machine descaling, since if any remains in the boiler it's no big deal, whereas smelly vinegar or cleancaf's detergent could be a problem even at low concentrations.

HX Machine Boilers

Descaling the boiler is much more of a headache. If you cook, you know that scale preferentially forms at the waterline. This means that filling the boiler with descaling solution only to the autofill line is not going to be very effective, since the descaler will barely be in contact with the bulk of the scale. Disconnecting the autofill (a wand like device sticking out of the top of the boiler with a single wire attached) will fill the boiler to a higher level and allow the descaler to work on this "rim".

In machines with a direct boiler tap, the boiler can be filled by opening the water tap, and letting the autofill refill the boiler with descaler. When that's done, close the tap, and disconnect the autofill for 30 seconds or so to fill the boiler a little above the regular water line. On machines without a direct boiler tap, the autofill has to be disconnected, and the fill may have to proceed by flushing the boiler through the steam wand. If there's an easily accessible drain, it may be easier to use it in conjunction with the autofill.

If you're draining via the steam wand, don't let the machine get too cold, otherwise the vacuum breaker will leak. Disconnecting the autofill at the sensor risks shifting the sensor's depth, so it's best to buy a spade lug and its mate, or an inline switch that is rated for 130C ambient, and use them to make a disconnect in the wire to the sensor. One can even extend the wiring so this can be done without removing the case (i.e. so it's reachable at the water tank).

Once the boiler is filled with descaler, leave it in for two and half hours with the machine off, or one hour with the machine on.

The descaler is flushed out using the same procedure that brought it in, either via the tap, steamwand or drain. Keep flushing and refilling until there's no more lemon taste. This may take about twice as much water as is usually in the boiler. It's best to refill the boiler with RO water (see below). Add 5% to 10% tap water to keep the autofill happy.

C. Boiler Flushing

Obviously, no one in their right minds would want to go through the hassle of doing a boiler descaling at monthly or bimonthly intervals. Fortunately, one can reduce the descaling requirement to virtually nothing, even when running the 90 mg/l hardness, 50 mg/l alkalinity water best for coffee by using this trick.

If the boiler autofill only runs to replenish water lost by steaming, it only amounts to a few ounces per day. Suppose the water in the boiler starts out very soft. Then these small additions of moderately hard water won't bring it to scaling levels for at least a week or so.

So once a week, put very soft water into your tank and flush the boiler with it until the water has been softened down. The flushing technique is the same as that described in the descaling section. Then put your regular neutral to moderately hard espresso water back in and enjoy your shots with complete confidence. If you regularly use boiler water for Americanos, etc., or do a lot of steaming, adjust the frequency of soft water flushing to match [see section 1.7]. If this is impossible due to very high use or boiler inaccessibility, you will have to go with a softer non-scaling water.

Straight RO can be used for this flushing since enough minerals will generally remain to operate the autofill sensor. If the pump doesn't go off due to low minerals, simply shut the machine and replace the RO water with the regular water. It will only take a few seconds of pumping to raise the mineral content enough to deactivate the autofill. Alternatively, add 5% to 10% tap water to make it conductive enough.

Even if boiler safe water is used, the boiler needs to be flushed occasionally. The frequency can be calculated using the data in Section 1.

If these procedures are followed, there's technically no need to descale the boiler at all. Nevertheless, an annual or biannual descaling is wise to pick up any stray scale that may have formed due to forgetfulness.

D. Choosing a Water Treatment

There's basically three choices: Using boiler safe water and never descaling. Using water close to 90 mg/l hardness, 50 mg/l alkalinity and descaling less frequently. Or using harder water and descaling more frequently. The choice mostly depends on how much the machine is used [see section 1.6], and how hard it is to descale.

Commercial operators have no choice. They must use boiler safe water, otherwise their machines would accumulate 5 grams of scale in anything from a few hours to a few days. Preventive descaling at these intervals is impossible. Home machine owners who never want to descale should follow the same course. The simplest way is to use RO water spiked with enough tap water to get to a 30 - 40 mg/l level. This course is absolutely safe provided the boiler is regularly flushed.

The hose end softeners sold by many espresso machine manufacturers do not, according to my measurements, make for scale free operation; but they will reduce descaling to quarterly frequency. My guess is that the cartridge style inline ion exchange units for plumbed in machines will be more effective, since they don't operate at elevated water temperatures.

I personally think home machine users are better served using neutral or harder water and preventively descaling. At home use levels, the 5 gram scale accumulation criterion will only require monthly to quarterly descaling, and the coffee taste will be at its best whenever the water is at 90/50 or above, since the machine will reduce it to that level by heating it. Whether or not to soften the water down to this level depends on how hard the tap water is; if the water is very hard, descaling could become a weekly chore, and such a partial softening could be preferable.

There's several ways to do this. The conceptually simplest is to boil the water for a few minutes; this removes hardness in excess of coffee levels. I use my Brita jug for all drinking water, since my water is cloudy from old pipes; its incomplete softening, or that of the hose end softener in a warm tank, also makes for a tasty espresso. Finally, tap water can be diluted with RO water to reach any hardness level one wants.

E. A Note to Commercial Operators

With conventional water inlet design, a commercial operation needs to run boiler safe water. This may have a slightly deleterious effect on espresso taste and still necessitates boiler blowdowns.

However, if the demand were out there, it shouldn't be all that difficult to design a better system. It would run two levels of water: RO water with a tad of minerals into the steam boiler, and a harder, tastier water into the heat exchangers. With proper plumbing, it should be simple to do a nightly citric acid flush of the heat exchangers, and a monthly boiler flush to keep them scale free.

F. A Water Treatment for Gaggia Home Machine Boilers

High alkalinity and low hardness water protects a Gaggia, since the alkalinity won't be reduced by scaling; while low alkalinity, high hardness water is deadly, since even if the original alkalinity is above the 50 mg/l safety limit, it will scale out, making the water and steam corrosive [section 1.8]. This leads to the following recommendations.

For those who are willing to be painstaking: 1. Use good coffee water (see above) 2. In the presence of calcium, steam temperature will reduce the alkalinity to a corrosive level. If you are using very high calcium water, even the brew temperature can reduce the alkalinity to corrosive levels. Therefore, after every espresso making session, flush the boiler and immediately turn the machine off. Descale on a regular schedule as explained above.

For those who want it foolproof at the slight expense of taste: Start with hard and high alkaline water (higher than 50mg/l), then soften it with an ion exchanger. The ion exchanger removes the scaling calcium and magnesium, but leaves the high alkalinity intact.

If you use a small ion exchanger connected to the machine's hose, don't forget to recharge it weekly. Avoid the Brita or Pur jug filter for this, since their use of hydrogen ion replacement makes the water slightly acidic, and leaves much of the calcium in.

If you have very soft water, or an RO system in the house, add a small pinch of baking soda (sodium bicarbonate) to every liter of water when you refill the tank. This will not be tasteable, and will supply about 70 mg/l of non-scaling alkalinity, more than enough to protect the boiler.

5. Web References

http://www.corrosion-doctors.org/

http://members.optushome.com.au/chelmon/Rbowkeep.htm

http://fins.actwin.com/aquatic-plants/month.9807/msg00114.html

http://fins.actwin.com/aquatic-plants/month.9810/msg00034.html

For further sources, Google on -- alkalinity $CaCO_3$ hardness -- this filters out the thousands of bozo pages that turn up for the more obvious searches like -- water hardness.