Boiler Water Treatment Chemicals, Feed, and Control - Perhaps It Is More Complicated Than We Thought

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Chemicals used to treat steam boiler systems are applied based upon the demand and mode of reaction of each chemical used. The theoretical versus actual consumption and the ease of control of these chemicals can vary according to many factors specific to each application.

Dosages and controls of chemicals are affected by how and where they are fed. The reaction and residual part of the chemical dosage calculation equation can affect control and results. Looking at the reaction percent helps decide whether it will work. The residual percent tells how easy it is to control. If all waters, all pretreatment equipment, all condensate, all feed equipment, all operators, and all boilers were the same, the chemical treatment would become routine, rather simple, easy, and reliable. However, since each steam system is unique in many ways, there are plenty of opportunities to provide application expertise by understanding each specific condition and the associated problems.

There are several different chemical approaches used to treat boilers and their selection and performance depend upon many factors. Some of these include:

1. Feedwater characteristics.
2. The type and reliability of external treatment.
3. Boiler type.
4. Boiler pressure and heat flux.
5. Steam load and variations in load.

6. Waterside condition of the boiler and current and long-term goals of the program such as cleaning up scale or maintaining present conditions.
7. Client and service provider preference.
8. Steam purity requirements.
9. Regulatory restrictions such as FDA requirements, other health and safety concerns, or process restrictions.
10. Feed, testing, and control needs or restrictions.
11. Economic considerations.
12. Boiler room layout and number of boilers.

The dosage of sodium sulfite or other oxygen scavengers may be calculated by looking at their reaction rate to remove the oxygen and then their residual dosage to provide a feedwater or boiler water residual.

Sodium Sulfite Example

The reaction rate is:

$$2Na_2SO_3 \text{ (7.88 ppm)} + O_2 \text{ (1 ppm)} \rightarrow 2Na_2SO_4$$

For the residual, 1.6 ppm Na_2SO_3 will yield 1 ppm SO_3.

The total calculation equation to remove residual oxygen and provide a boiler water residual is:

(Feedwater O_2 x 7.88) + (1.6 x Boiler Water SO_3 Residual) / Feedwater Cycles = Feedwater Dosage of 100% sodium sulfite in ppm.

Spreadsheets can be made as shown at the end of the article that illustrate the impact of changes in variables such as dissolved oxygen concentration, feedwater cycles, steam production, desired sulfite residual, and applied dosages. Examine the results shown on the examples.

If the dissolved oxygen concentration varies from 0.01 ppm to 1.0 ppm in the feedwater, to maintain the 30 ppm boiler water residual, the daily dosage demand increases by almost 500% and the reaction demand increases from 3.9% of the dosage to 80%. Clearly a variable oxygen content is very difficult and costly to control.

Looking at cycle control reveals that even though the dosage to obtain a residual may increase dramatically at low cycles, only a small portion of the sulfite total dosage is required to remove oxygen, so residual control is not as important if the deaerator is operating properly. The reaction dosage at 5 to 50 cycles only varies from 0.8% to 7.6% of the total required dosage.

Changing the residual in the boiler if the deaerator is operating properly can change consumption significantly, but should have little impact on results, unless the deaerator dissolved oxygen level spikes above the 0.01 ppm level.

Variations in deaerator oxygen removal obviously would have a great impact on sulfite consumption. If the dosage is fixed at 1.92 ppm at 25 cycles, and the oxygen content from the deaerator increases from 0.01 ppm to 0.1 ppm, the sulfite residual will drop from 29 ppm to 18 ppm. The reaction demand increased from 4.1% of the total dosage to 41%.

Clearly, the control of sulfite feed and maintaining control will depend upon the specifics of each system. A deaerator that provides consistent, low oxygen residuals will be much easier to control than one that is giving unsteady results. Feedwater heaters with variable oxygen levels will be nearly impossible to control economically. Where dissolved oxygen levels are high or variable and when using feedwater heaters, applying a passivator such as erythorbate or DEHA would be a valuable addition to the sulfite.

Sodium Hexametaphosphate

Sodium hexametaphosphate is a commonly used source of orthophosphate anion used to precipitate calcium in low-pressure boilers. With dispersants the calcium phosphate becomes a fluidized sludge capable of being blown down and out of the boiler before the calcium can form a deposit.

Example

The reaction rate is the first part of the equation and the residual the second part:

$$[\ (0.72 \text{ x Ca} + 1.08 \text{ x } PO_4/ \text{ Feedwater Cycles})\ ]$$

= ppm of 100% sodium hexametaphosphate in feedwater.

Again, spreadsheets can be made varying calcium in the feedwater, cycles, steam load, changing desired phosphate residuals, or holding the phosphate dosage constant.

Examining the spreadsheets reveals that if the feedwater calcium level is low, most of the product dosage goes to provide residual in the boiler water. If the calcium level starts to become significant, the reaction portion of the equation may become the major demand for the product. Obviously, control will be difficult with variations in feedwater calcium just as with variation with oxygen for sulfite control.

If the feedwater cycles are varied from 5 to 50 cycles, the dosage requirement changes by over a factor of 8, with most of the demand coming from the residual portion of the calculation. So even though residual may change significantly, if calcium is low and consistent, there is enough phosphate to satisfy the demand, and calcium carbonate scale should be avoided even with wild changes in blowdown rates.

Chelant Treatment

EDTA dosage requirements and variations will be similar to phosphate in that there is a reaction and residual portion to the dosage calculation:

$$\frac{(\text{Feedwater hardness}) \times (3.8)}{\frac{\%\ \text{active}}{100}} + \frac{\text{ppm EDTA desired residual}}{(\text{feedwater cycles}) \times \frac{\%\ \text{active}}{100}} = \text{ppm EDTA Product}$$

Economical control would again be very difficult with fluctuations in feedwater hardness.

Looking at the spreadsheet at the end of the paper shows that the EDTA dosage demand can easily increase twenty-fold with poor feedwater hardness control. Phosphate treatment would be easier to control with variations in feedwater hardness.

Blended Products

The variation in phosphate demand or chelant demand and changes in cycles makes phosphate/polymer or chelant/polymer blends difficult to control. These products are best designed for a specific and consistent condition. A formulated product should be evaluated for each system and anticipated fluctuations to see how the polymer level varies if phosphate or EDTA is used as the control.

Example

A boiler product contains 10% EDTA and 15% polymer. It is applied to a boiler operating at 20 cycles with 0.1 ppm feedwater hardness. Feedwater dosage is 8.8 ppm to yield 10 ppm free EDTA and 26 ppm polymer.

If the hardness goes up to 1 ppm or the product is used in another system where the hardness is 1 ppm, the feedwater dosage increases to 43 ppm to obtain 10 ppm free EDTA. This would yield a high polymer level of 129 ppm. Polymer overfeed is expensive and high polymer levels can cause boiler water carryover with their surface-active properties that occur at high concentrations.

Other Chemical Feed and Control Considerations

How and where the various boiler chemicals are fed can affect their performance and control.

a. Oxygen scavengers are best fed to the storage section of the deaerator or feedwater tank. In most low-pressure industrial boiler systems, if oxygen remains in the feedwater and enters the boiler, it is too late to remove all of the oxygen and protect the boiler and condensate from oxygen corrosion. A residual of sulfite or other oxygen scavenger in the boiler cannot chemically reduce all of the oxygen before it escapes with the steam or reacts with the metal surfaces.

The oxygen scavenger should be pumped either continuously or paced with makeup into the deaerator so that there is a positive residual at all times in the deaerator. Consideration should be given to see where the makeup and condensate enter the deaerator. Often times the high pressure condensate enters directly into the storage section. If the condensate contains oxygen, intermittently high dissolved oxygen levels in the feedwater may occur. Also sudden load changes can allow temporary high dissolved oxygen levels. Even with sulfite feed to the deaerator, but especially if sulfite is fed to the boiler, the boiler sulfite residual may not show a big change as oxygen is released into the steam or corrodes the boiler before it is reduced chemically. Dissolved oxygen testing in the feedwater would be the best tool to insure consistently low dissolved oxygen levels and adequate chemical feed and control.

How condensate is returned, the level controls on the deaerator, and the proportion of makeup to condensate can affect deaerator performance and therefore results. If there is a relatively small deaerator volume and the amount of condensate return varies throughout the day or night, load and performance can change. Dissolved oxygen content and feedwater oxygen scavenger concentration should be checked under the changing conditions.

These situations could explain why one system sees corrosion and another does not, even though it appears to be the same treatment and control.

b. **Chemical feed should be continuous**. Chemical pumping rates can create problems especially for neat feed set ups. Using on/off feed systems such as a recycle timer can create problems. Chemical feed pumps should be sized or product strengths should be adjusted to allow continuous feed.

Steam and carbon dioxide leave continuously, so setting up a neutralizing amine pump to feed intermittently can lead to wide variations in condensate pH control. If sampling is done from a condensate receiver, the tank volume may buffer the variations and the changes may not be noticed, but corrosion could be occurring to areas of the piping that see the rapidly changing pH.

If polymeric dispersants, phosphonates, phosphate, or chelants are fed intermittently into the feedwater using a recycle timer, and the amines are not fed continuously, a cycle of iron slugs returning in the condensate can be followed by slugs of high dispersancy cleaning of the iron from the deaerator and dragging it into the boiler.

c. **Load changes** can affect chemical concentrations when the chemical feed is base fed. Example: Steam production of one million lbs./day; 4% blowdown; 20% active boiler polymer product fed at 5 pounds per day. The calculated daily average polymer concentration would be 24 ppm. Assume peak plant production load is 60,000 lbs./hr., but during the overnight hours the load is only 5,000 lbs./hr. If the dispersant is being fed continuously over the 24 hours, during the 8-hour low load period, the boiler polymer concentration would have increased to over 200 ppm. Upon high fire when production resumes, carryover is very possible because of over concentrating the polymeric dispersant.

   Chemical feed needs to be paced to steam production, especially where significant load changes occur.

d. **Carbon dioxide** can concentrate in steam and condensate making neutralizing amine treatment impractical. Carbon dioxide levels can be relatively low in steam exiting a boiler at only a few ppm, but if there are areas where it becomes “trapped” and can accumulate, concentrations can reach extremely high levels into the hundreds or even thousands of ppm.

   CO_2 is a non-condensable gas. It has a distribution ratio in the steam piping and condenses at points throughout the system. At the boiling point, the solubility of the gas in water is extremely low. The solubility of the CO_2 is actually lower in the condensate than it is in the steam. For the CO_2 to escape from the steam into the water it will accumulate in the steam space just above the water level until the partial pressure becomes high enough for the CO_2 in the incoming steam to be able to exit into the condensate. This creates a steady state condition of CO_2 coming in and exiting, but an area of severe localized corrosion occurs where the carbon dioxide concentration is high.

   The highest CO_2 concentration normally occurs just above the condensate water level. If there is an area where condensation is occurring and running down pipes or the sides of vessels, the CO_2 concentration will be very high and the pH will be about 5.3 – 5.5 in that location creating high corrosion rates.

The solubility of CO_2 increases dramatically as the condensate temperature falls below 212 °F. When there is an accumulation of CO_2 in an area and the condensate temperature is relatively low, the amount of carbon dioxide going into solution will be extremely high. Where low-pressure steam is used that contains CO_2 and the heat exchange process has relatively close temperature differentials between the steam and the condensate, there is potential for high uptake of the CO_2 into the condensate and localized low pH.

Neutralizing amines are selected in an effort to condense in the right concentrations to carbon dioxide condensation levels throughout the steam system. Neutralizing amines cannot control corrosion where this localized accumulation of carbon dioxide occurs since the high CO_2 overwhelms the demand for the amine. Even point source addition of amine may not be able to satisfy the demand.

Where the concentrating effect of CO_2 occurs, methods of reducing the problem include eliminating or minimizing CO_2 in the steam, venting off the CO_2 in the localized area, eliminating condensate in the area, applying a filming amine or metal passivator, or using higher temperature steam and increasing condensate temperature to reduce the CO_2 content in the condensate.

Watertube Boiler Load Versus Design Capacity

In watertube boilers, the water flow rate or "water wash" through the tubes provides the movement of dispersed suspended solids to carry through the tubes and to be removed by blowdown. When boilers operate at loads substantially below design load, there can be little movement through some tubes that don't know whether to be downcomers or risers. This can create the opportunity for the conditioned sludge to bake onto those tubes. Where this condition exists, solubilizing programs should be considered and/or very low hardness and iron levels in the feedwater should be maintained. Certainly inspect all the tubes during inspections checking these stagnant areas.

Chemical Feed Points and Short Circuiting

Boiler dispersants are best fed to the deaerator or feedwater where the pH is lower than the boiler water. This gives the best conditions for dispersion and transport of iron and suspended solids through and out of the boiler. The injection points of chemicals should be selected to make full use of them. If the chemical is entering with the feedwater or chemical feed line, make sure the surface blowdown line is not directly next to the entry point, which would allow chemical to leave directly with blowdown. If actual chemical consumption is higher than theoretical, this could be one explanation.

If stainless steel injection quills are required, make sure they are in place and extend into the water to avoid corrosion by reducing agents or chelating chemicals.

Firetube Flow Pattern

Feedwater enters on the side of firetube boilers near the center and about a third of the way up from the bottom. If residual oxygen is in the feedwater, pitting corrosion will likely occur in the tubes right near the feedwater entry point. Don't assume there is not a corrosion problem based upon inspecting only the top rows of tubes as seen from the manway. Check the area around the feedwater entry point. The concern is greatest with feedwater heaters. I have seen sulfite residuals well maintained in boilers with sulfite residuals in the feedwater, but corrosion on the tubes immediately near the feedwater entry point. A continuous dissolved oxygen analyzer on the feedwater revealed residual oxygen. Corrosion coupons in the feedwater showed pitting corrosion in less than an hour.

The relatively cold feedwater containing residual hardness will fall to both ends of the boiler and then rise. Initial precipitation of the minerals will occur here, which is also the hottest part of the boiler. Scale and sludge deposition will most likely occur near the entry point and the high heat area and sludge accumulation will concentrate in the ends of the boiler where the water is first directed. Check for deposition on these lower tubers and on the bottoms of the tubes. Minimize iron and hardness levels and use chelating agents.

Attemperation

As a rule, the water used for desuperheating steam should be the same quality as the steam. High quality condensate or mixed bed demineralized water are good choices. It is common to see boiler feedwater used if the quality is high since the boiler feedwater pump can be used to supply the attemperation water, thereby reducing the expense of an additional pump. If feedwater is used, chemicals added to the deaerator or feedwater before the attemperation take-off point should be volatile. For FDA plants, erythorbate that is pH neutralized with amine is used.

Intermittent Boiler Water Carryover

Steam purity is the measurement of dissolved solids in the steam and steam quality is a measurement of moisture content. Both watertube and firetube boilers can experience variances in the degree of carryover based upon steam load and changes in load. Detecting carryover is not always easy. Chemicals can contribute to foaming and priming in boilers. High total dissolved solids along with high alkalinities are potential culprits. Oil and other contaminants can create carryover. High polymer concentrations as stated earlier have been shown to cause problems.

Continuous or regular short interval testing of condensed steam may be necessary to catch carryover as it may occur in short spurts. Moisture in the steam can lead to impingement on steam lines and steam traps. Black iron deposits in traps and condensate receivers can be an indicator of this problem. If intermittent carryover is occurring, see if the water level can be lowered to correct the problem.

To determine if the applied chemicals are contributing to the problem, discontinue chemical feed until all of it has been purged from the boiler and retest for carryover. A good test is to compare sodium and silica in the boiler water to that in the condensed steam.

Summary

Chemical treatment of boilers and chemical selection should be based upon each individual system. Similar programs can perform very differently depending upon the particular boiler system and operation.

Theoretical usages and actual consumptions should regularly be compared and discrepancies justified. The dosages and residuals for the range of situations expected for the system should be calculated to determine what problems or concerns there may be and how well the program can be controlled.

Sodium Sulfte Calculations

Vary DO

								Dosage Proportions	
SO3 Residual	DO	Cycles	Steam lbs/day	Reaction Demand ppm	Residual Dose ppm	Total Dose ppm	Daily lbs.	% Reaction	% Residual
30	**0.01**	**25**	**1,000,000**	**0.08**	**1.92**	**2.00**	**2.08**	**3.9%**	**96.1%**
30	0.05	25	1,000,000	0.39	1.92	2.31	2.41	17.0%	83.0%
30	0.1	25	1,000,000	0.79	1.92	2.71	2.82	29.1%	70.9%
30	0.5	25	1,000,000	3.94	1.92	5.86	6.10	67.2%	32.8%
30	1	25	1,000,000	7.88	1.92	9.80	10.21	80.4%	19.6%

Vary Blowdown

								Dosage Proportions	
SO3 Residual	DO	Cycles	Steam lbs/day	Reaction Demand ppm	Residual Dose ppm	Total Dose ppm	Daily lbs.	% Reaction	% Residual
30	0.01	5	1,000,000	0.08	9.6	9.68	12.10	0.8%	99.2%
30	0.01	10	1,000,000	0.08	4.8	4.88	5.42	1.6%	98.4%
30	0.01	20	1,000,000	0.08	2.4	2.48	2.61	3.2%	96.8%
30	**0.01**	**25**	**1,000,000**	**0.08**	**1.92**	**2.00**	**2.08**	**3.9%**	**96.1%**
30	0.01	50	1,000,000	0.08	0.96	1.04	1.06	7.6%	92.4%

Vary Residual

								Dosage Proportions	
SO3 Residual	DO	Cycles	Steam lbs/day	Reaction Demand ppm	Residual Dose ppm	Total Dose ppm	Daily lbs.	% Reaction	% Residual
5	0.01	25	1,000,000	0.08	0.32	0.40	0.42	19.8%	80.2%
10	0.01	25	1,000,000	0.08	0.64	0.72	0.75	11.0%	89.0%
20	0.01	25	1,000,000	0.08	1.28	1.36	1.42	5.8%	94.2%
30	**0.01**	**25**	**1,000,000**	**0.08**	**1.92**	**2.00**	**2.08**	**3.9%**	**96.1%**
50	0.01	25	1,000,000	0.08	3.2	3.28	3.42	2.4%	97.6%

Vary Steam

								Dosage Proportions	
SO3 Residual	DO	Cycles	Steam lbs/day	Reaction Demand ppm	Residual Dose ppm	Total Dose ppm	Daily lbs.	% Reaction	% Residual
30	0.01	25	250,000	0.08	1.92	2.00	0.52	3.9%	96.1%
30	0.01	25	500,000	0.08	1.92	2.00	1.04	3.9%	96.1%
30	0.01	25	750,000	0.08	1.92	2.00	1.56	3.9%	96.1%
30	**0.01**	**25**	**1,000,000**	**0.08**	**1.92**	**2.00**	**2.08**	**3.9%**	**96.1%**
30	0.01	25	2,000,000	0.08	1.92	2.00	4.16	3.9%	96.1%

Constant DO; Vary Sulfite Dosage

								Dosage Proportions	
SO3 Residual	DO	Cycles	Steam lbs/day	Reaction Demand ppm	Residual Dose ppm	Total Dose ppm	Daily lbs.	% Reaction	% Residual
6	0.01	25	1,000,000	0.08	0.40	0.48	0.50	16.4%	83.6%
14	0.01	25	1,000,000	0.08	0.88	0.96	1.00	8.2%	91.8%
29	**0.01**	**25**	**1,000,000**	**0.08**	**1.84**	**1.92**	**2.00**	**4.1%**	**95.9%**
44	0.01	25	1,000,000	0.08	2.80	2.88	3.00	2.7%	97.3%
59	0.01	25	1,000,000	0.08	3.76	3.84	4.00	2.1%	97.9%

Vary DO; Constant Sulfite Dosage

								Dosage Proportions	
SO3 Residual	DO	Cycles	Steam lbs/day	Reaction Demand ppm	Residual Dose ppm	Total Dose ppm	Daily lbs.	% Reaction	% Residual
29	0.01	25	1,000,000	0.08	1.84	1.92	2.00	4.1%	95.9%
24	0.05	25	1,000,000	0.39	1.53	1.92	2.00	20.5%	79.5%
18	0.1	25	1,000,000	0.79	1.13	1.92	2.00	41.0%	59.0%
0	0.5	25	1,000,000	3.94	0.00	1.92	2.00	100.0%	0.0%
0	1	25	1,000,000	7.88	0.00	1.92	2.00	100.0%	0.0%

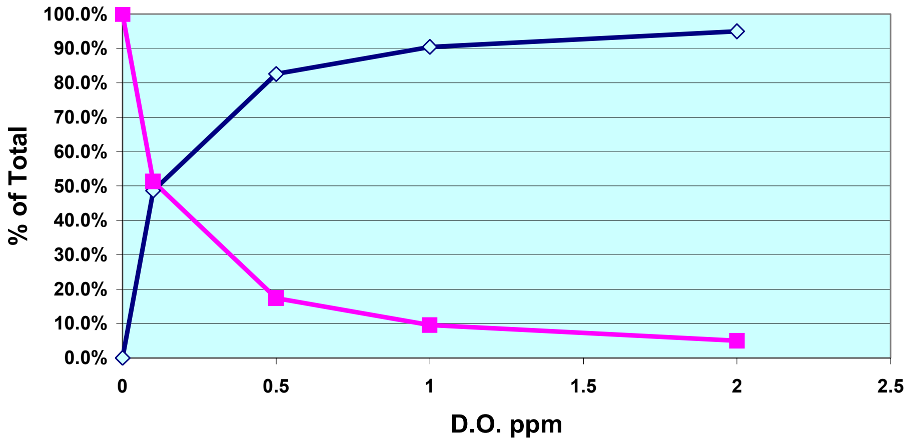
Vary Cycles; Constant Sulfite Dosage on Good DA

								Dosage Proportions	
SO3 Residual	DO	Cycles	Steam lbs/day	Reaction Demand ppm	Residual Dose ppm	Total Dose ppm	Daily lbs.	% Reaction	% Residual
5	0.01	5	1,000,000	0.08	1.52	1.60	2.00	4.9%	95.1%
11	0.01	10	1,000,000	0.08	1.72	1.80	2.00	4.4%	95.6%
23	0.01	20	1,000,000	0.08	1.82	1.90	2.00	4.1%	95.9%
29	0.01	25	1,000,000	0.08	1.84	1.92	2.00	4.1%	95.9%
59	0.01	50	1,000,000	0.08	1.88	1.96	2.00	4.0%	96.0%

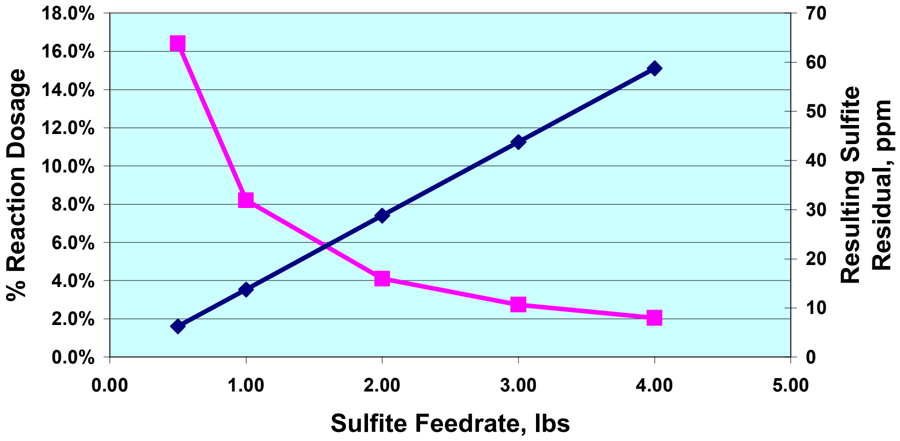
Vary Cycles; Constant Sulfite Dosage on Poor Deaeration

								Dosage Proportions	
SO3 Residual	DO	Cycles	Steam lbs/day	Reaction Demand ppm	Residual Dose ppm	Total Dose ppm	Daily lbs.	% Reaction	% Residual
2	0.75	5	1,000,000	5.91	0.49	6.40	8.00	92.3%	7.7%
8	0.75	10	1,000,000	5.91	1.29	7.20	8.00	82.1%	17.9%
21	0.75	20	1,000,000	5.91	1.69	7.60	8.00	77.8%	22.2%
28	0.75	25	1,000,000	5.91	1.77	7.68	8.00	77.0%	23.0%
60	0.75	50	1,000,000	5.91	1.93	7.84	8.00	75.4%	24.6%

Sodium Sulfite Reaction % and Residual % vs. Dissolved Oxygen



Sodium Sulfite Residual vs. Feed Rate and Reaction %



100% EDTA Calculations

Vary Hardness

								Dosage Proportions	
EDTA Residual	Hardness	Cycles	Steam lbs/day	Reaction Demand ppm	Residual Dose ppm	Total Dose ppm	Daily lbs.	% Reaction	% Residual
10	0	25	1,000,000	0.00	0.40	0.40	0.42	0.0%	100.0%
10	0.1	25	1,000,000	0.38	0.40	0.78	0.81	48.7%	51.3%
10	0.5	25	1,000,000	1.90	0.40	2.30	2.40	82.6%	17.4%
10	1	25	1,000,000	3.80	0.40	4.20	4.38	90.5%	9.5%
10	2	25	1,000,000	7.60	0.40	8.00	8.33	95.0%	5.0%

Vary Blowdown

								Dosage Proportions	
EDTA Residual	Hardness	Cycles	Steam lbs/day	Reaction Demand ppm	Residual Dose ppm	Total Dose ppm	Daily lbs.	% Reaction	% Residual
10	0.5	5	1,000,000	1.90	2.00	3.90	4.88	48.7%	51.3%
10	0.5	10	1,000,000	1.90	1.00	2.90	3.22	65.5%	34.5%
10	0.5	20	1,000,000	1.90	0.50	2.40	2.53	79.2%	20.8%
10	0.5	25	1,000,000	1.90	0.40	2.30	2.40	82.6%	17.4%
10	0.5	50	1,000,000	1.90	0.20	2.10	2.14	90.5%	9.5%

Vary Residual

								Dosage Proportions	
EDTA Residual	Hardness	Cycles	Steam lbs/day	Reaction Demand ppm	Residual Dose ppm	Total Dose ppm	Daily lbs.	% Reaction	% Residual
1	0.5	25	1,000,000	1.90	0.04	1.94	2.02	97.9%	2.1%
2	0.5	25	1,000,000	1.90	0.08	1.98	2.06	96.0%	4.0%
5	0.5	25	1,000,000	1.90	0.20	2.10	2.19	90.5%	9.5%
10	0.5	25	1,000,000	1.90	0.40	2.30	2.40	82.6%	17.4%
20	0.5	25	1,000,000	1.90	0.80	2.70	2.81	70.4%	29.6%

Vary Steam

								Dosage Proportions	
EDTA Residual	Hardness	Cycles	Steam lbs/day	Reaction Demand ppm	Residual Dose ppm	Total Dose ppm	Daily lbs.	% Reaction	% Residual
10	0.5	25	250,000	1.90	0.40	2.30	0.60	82.6%	17.4%
10	0.5	25	500,000	1.90	0.40	2.30	1.20	82.6%	17.4%
10	0.5	25	750,000	1.90	0.40	2.30	1.80	82.6%	17.4%
10	0.5	25	1,000,000	1.90	0.40	2.30	2.40	82.6%	17.4%
10	0.5	25	2,000,000	1.90	0.40	2.30	4.79	82.6%	17.4%

Constant Hardness; Vary EDTA Dosage

								Dosage Proportions	
EDTA Residual	Hardness	Cycles	Steam lbs/day	Reaction Demand ppm	Residual Dose ppm	Total Dose ppm	Daily lbs.	% Reaction	% Residual
1	0.5	25	1,000,000	1.90	0.02	1.92	2.00	99.0%	1.0%
8	0.5	25	1,000,000	1.90	0.31	2.21	2.30	86.1%	13.9%
25	0.5	25	1,000,000	1.90	0.98	2.88	3.00	66.0%	34.0%
37	0.5	25	1,000,000	1.90	1.46	3.36	3.50	56.5%	43.5%
49	0.5	25	1,000,000	1.90	1.94	3.84	4.00	49.5%	50.5%

Vary Hardness; Constant EDTA Dosage

								Dosage Proportions	
EDTA Residual	Hardness	Cycles	Steam lbs/day	Reaction Demand ppm	Residual Dose ppm	Total Dose ppm	Daily lbs.	% Reaction	% Residual
48	0	25	1,000,000	0.00	1.92	1.92	2.00	0.0%	100.0%
39	0.1	25	1,000,000	0.38	1.54	1.92	2.00	19.8%	80.2%
1	0.5	25	1,000,000	1.90	0.02	1.92	2.00	99.0%	1.0%
0	1	25	1,000,000	3.80	0.00	1.92	2.00	100.0%	0.0%
0	2	25	1,000,000	7.60	0.00	1.92	2.00	100.0%	0.0%

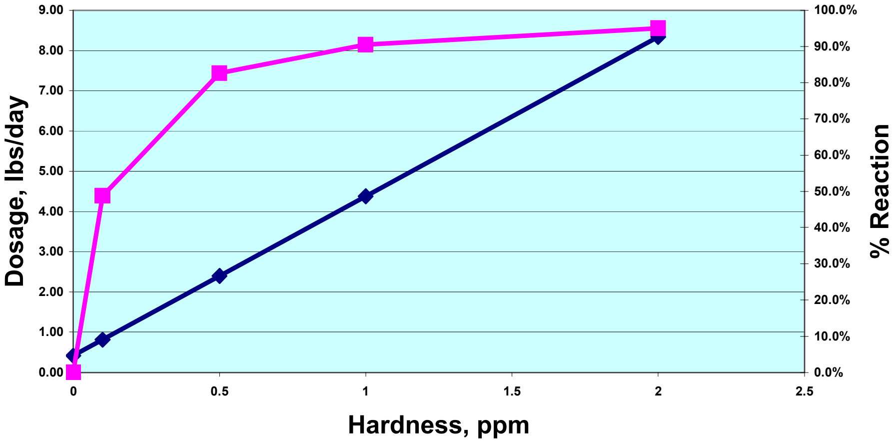
Vary Cycles; Constant EDTA Dosage and Constant Hardness

								Dosage Proportions	
EDTA Residual	Hardness	Cycles	Steam lbs/day	Reaction Demand ppm	Residual Dose ppm	Total Dose ppm	Daily lbs.	% Reaction	% Residual
3	0.5	5	1,000,000	1.90	0.50	2.40	3.00	79.2%	20.8%
8	0.5	10	1,000,000	1.90	0.80	2.70	3.00	70.4%	29.6%
19	0.5	20	1,000,000	1.90	0.95	2.85	3.00	66.7%	33.3%
25	0.5	25	1,000,000	1.90	0.98	2.88	3.00	66.0%	34.0%
52	0.5	50	1,000,000	1.90	1.04	2.94	3.00	64.6%	35.4%

Vary Cycles; Constant EDTA Dosage with Poor Hardness Removal

								Dosage Proportions	
EDTA Residual	Hardness	Cycles	Steam lbs/day	Reaction Demand ppm	Residual Dose ppm	Total Dose ppm	Daily lbs.	% Reaction	% Residual
2	2	5	1,000,000	7.60	0.40	8.00	10.00	95.0%	5.0%
14	2	10	1,000,000	7.60	1.40	9.00	10.00	84.4%	15.6%
38	2	20	1,000,000	7.60	1.90	9.50	10.00	80.0%	20.0%
50	2	25	1,000,000	7.60	2.00	9.60	10.00	79.2%	20.8%
110	2	50	1,000,000	7.60	2.20	9.80	10.00	77.6%	22.4%

EDTA Dosage and Reaction vs. Feedwater Hardness



Sodium Hexametaphosphate Calculations

Vary Calcium

								Dosage Proportions	
PO4 Residual	Calcium	Cycles	Steam lbs/day	Reaction Demand ppm	Residual Dose ppm	Total Dose ppm	Daily lbs.	% Reaction	% Residual
30	0	25	1,000,000	0.00	1.30	1.30	1.35	0.0%	100.0%
30	0.1	25	1,000,000	0.07	1.30	1.37	1.43	5.3%	94.7%
30	0.5	25	1,000,000	0.36	1.30	1.66	1.73	21.7%	78.3%
30	1	25	1,000,000	0.72	1.30	2.02	2.10	35.7%	64.3%
30	2	25	1,000,000	1.44	1.30	2.74	2.85	52.6%	47.4%

Vary Blowdown

								Dosage Proportions	
PO4 Residual	Calcium	Cycles	Steam lbs/day	Reaction Demand ppm	Residual Dose ppm	Total Dose ppm	Daily lbs.	% Reaction	% Residual
30	0.5	5	1,000,000	0.36	6.48	6.84	8.55	5.3%	94.7%
30	0.5	10	1,000,000	0.36	3.24	3.60	4.00	10.0%	90.0%
30	0.5	20	1,000,000	0.36	1.62	1.98	2.08	18.2%	81.8%
30	0.5	25	1,000,000	0.36	1.30	1.66	1.73	21.7%	78.3%
30	0.5	50	1,000,000	0.36	0.65	1.01	1.03	35.7%	64.3%

Vary Residual

								Dosage Proportions	
PO4 Residual	Calcium	Cycles	Steam lbs/day	Reaction Demand ppm	Residual Dose ppm	Total Dose ppm	Daily lbs.	% Reaction	% Residual
5	0.5	25	1,000,000	0.36	0.22	0.58	0.60	62.5%	37.5%
10	0.5	25	1,000,000	0.36	0.43	0.79	0.83	45.5%	54.5%
20	0.5	25	1,000,000	0.36	0.86	1.22	1.28	29.4%	70.6%
30	0.5	25	1,000,000	0.36	1.30	1.66	1.73	21.7%	78.3%
50	0.5	25	1,000,000	0.36	2.16	2.52	2.63	14.3%	85.7%

Vary Steam

								Dosage Proportions	
PO4 Residual	Calcium	Cycles	Steam lbs/day	Reaction Demand ppm	Residual Dose ppm	Total Dose ppm	Daily lbs.	% Reaction	% Residual
30	0.5	25	250,000	0.36	1.30	1.66	0.43	21.7%	78.3%
30	0.5	25	500,000	0.36	1.30	1.66	0.86	21.7%	78.3%
30	0.5	25	750,000	0.36	1.30	1.66	1.29	21.7%	78.3%
30	0.5	25	1,000,000	0.36	1.30	1.66	1.73	21.7%	78.3%
30	0.5	25	2,000,000	0.36	1.30	1.66	3.45	21.7%	78.3%

Constant Calcium; Vary Phosphate Dosage

								Dosage Proportions	
PO4 Residual	Calcium	Cycles	Steam lbs/day	Reaction Demand ppm	Residual Dose ppm	Total Dose ppm	Daily lbs.	% Reaction	% Residual
3	0.5	25	1,000,000	0.36	0.12	0.48	0.50	75.0%	25.0%
14	0.5	25	1,000,000	0.36	0.60	0.96	1.00	37.5%	62.5%
36	0.5	25	1,000,000	0.36	1.56	1.92	2.00	18.8%	81.3%
58	0.5	25	1,000,000	0.36	2.52	2.88	3.00	12.5%	87.5%
81	0.5	25	1,000,000	0.36	3.48	3.84	4.00	9.4%	90.6%

Vary Calcium; Constant Phosphate Dosage

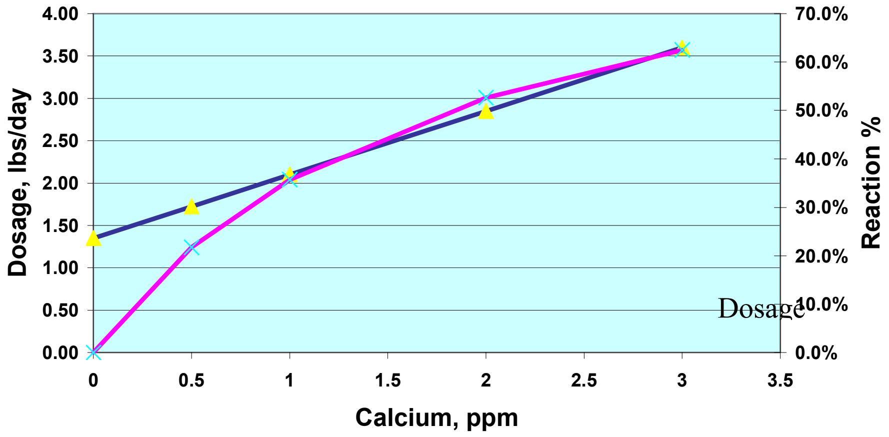
								Dosage Proportions	
PO4 Residual	Calcium	Cycles	Steam lbs/day	Reaction Demand ppm	Residual Dose ppm	Total Dose ppm	Daily lbs.	% Reaction	% Residual
44	0	25	1,000,000	0.00	1.92	1.92	2.00	0.0%	100.0%
43	0.1	25	1,000,000	0.07	1.85	1.92	2.00	3.8%	96.3%
36	0.5	25	1,000,000	0.36	1.56	1.92	2.00	18.8%	81.3%
28	1	25	1,000,000	0.72	1.20	1.92	2.00	37.5%	62.5%
11	2	25	1,000,000	1.44	0.48	1.92	2.00	75.0%	25.0%

Vary Cycles; Constant Phosphate Dosage and Constant Calcium

								Dosage Proportions	
PO4 Residual	Calcium	Cycles	Steam lbs/day	Reaction Demand ppm	Residual Dose ppm	Total Dose ppm	Daily lbs.	% Reaction	% Residual
6	0.5	5	1,000,000	0.36	1.24	1.60	2.00	22.5%	77.5%
13	0.5	10	1,000,000	0.36	1.44	1.80	2.00	20.0%	80.0%
29	0.5	20	1,000,000	0.36	1.54	1.90	2.00	18.9%	81.1%
36	0.5	25	1,000,000	0.36	1.56	1.92	2.00	18.8%	81.3%
74	0.5	50	1,000,000	0.36	1.60	1.96	2.00	18.4%	81.6%

Vary Cycles; Constant Phosphate Dosage with Poor Calcium Removal

								Dosage Proportions	
PO4 Residual	Calcium	Cycles	Steam lbs/day	Reaction Demand ppm	Residual Dose ppm	Total Dose ppm	Daily lbs.	% Reaction	% Residual
4	2	5	1,000,000	1.44	0.96	2.40	3.00	60.0%	40.0%
12	2	10	1,000,000	1.44	1.26	2.70	3.00	53.3%	46.7%
26	2	20	1,000,000	1.44	1.41	2.85	3.00	50.5%	49.5%
33	2	25	1,000,000	1.44	1.44	2.88	3.00	50.0%	50.0%
69	2	50	1,000,000	1.44	1.50	2.94	3.00	49.0%	51.0%



Sodium Hexametaphosphate Dosage and Reaction vs. Feedwater Calcium