

Modeling Software for Predicting Water and Steam Cycle Chemistry

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KEYWORDS: condensate, steam, boiler water, corrosion, chemical treatment, neutralizing amines, organic acids, chlorides, computer modeling

ABSTRACT

Chemistry Modeling System (CMS) software has been available for nearly four decades and has been successfully used in industry to evaluate, troubleshoot and optimize steam and condensate system operations. The CMS program has evolved over the past few years and has been upgraded with streamlined data input features, new treatment product and chemical databases, and expanded functionality. These upgrades to the CMS program have enabled users to leverage the software to help solve complex problems related to boiler feedwater and boiler water chemistry.

INTRODUCTION

Boiler feedwater, steam, and condensate systems are often quite complex and require effective chemical treatments to minimize corrosion damage, reduce potential for costly repairs, and to minimize lost production caused by unscheduled plant shutdowns. Volatile alkalizing agents such as ammonia and neutralizing amines are commonly employed for this purpose. These chemicals volatilize and travel throughout the steam-water circuit. They function by neutralizing carbonic acid and by elevating the pH of the condensate making it less corrosive.

The goal of a successful condensate chemical treatment program is to elevate the pH of the condensate throughout the steam-condensate circuit, raising the pH sufficiently at each condensation point so that the entire system will be protected from corrosion. Before computerized models were available, users of condensate treatment chemicals were faced with the difficult task of trying to select the best chemical treatment formulation for a given system. Decisions about what product to use were often based on the user's intuition or experience, the requirements of a licensee, or by trying to guess how the active ingredients would distribute and recycle via condensate return within the system. Users would frequently select products with both low and high volatility ingredients with the expectation that this type of product would protect the initial condensation points as well as the points furthest away from the steam generator. Selecting and applying amine products in this fashion often resulted in there being some areas of the plant that were not adequately protected. Once undertreated areas were identified (often after equipment or line failures), satellite chemical feed points would then need to be added in order to protect these areas of the plant. Overall, the product selection and application processes were somewhat arbitrary, and required a significant amount of experimentation to develop the optimum treatment program.

Another approach that was sometimes used to develop a chemical treatment strategy for steam-condensate systems was to perform in-plant testing with various neutralizing amines. Chemical formulations containing a mix of different neutralizing amines would be dosed into the system from a central location and samples would be drawn from several locations throughout the plant. Samples were then analyzed at each sample point for pH and conductivity and were then shipped to a laboratory for specific amine analysis. Once all the data was compiled, a treatment program could be recommended based on how each amine was distributed in the system and how much carbonic acid was present at each sample location. This was certainly a more scientific approach to condensate treatment program design, but still required a significant amount of planning, sampling, and analytical effort.

To streamline and improve the condensate treatment program design process, a computer-based tool called "Chemistry Modeling System" (CMS) was developed. The CMS program has been used extensively for nearly 40 years to help design condensate treatment programs and to troubleshoot existing condensate treatment applications (Hepp & Bornak, 1987; Robinson, 1994; Kluck & Robinson, 2010; Robinson & Robinson, 2019). Over this time, the CMS tool has been upgraded to include a wider set of neutralizing amines, various internal boiler treatment chemistries, as well as some common contaminant species such as chloride, sodium, and organic acids. With these additions, the CMS tool has become useful in other applications. These include modeling of boiler water chemistry and designing chemical treatments to combat flow-

accelerated corrosion (Kluck et al., 2011; Robinson, Carvalho & Robinson, 2012). This paper describes several case studies in which the CMS program was used to troubleshoot or optimize boiler water internal treatment programs where high purity makeup is being used.

BACKGROUND

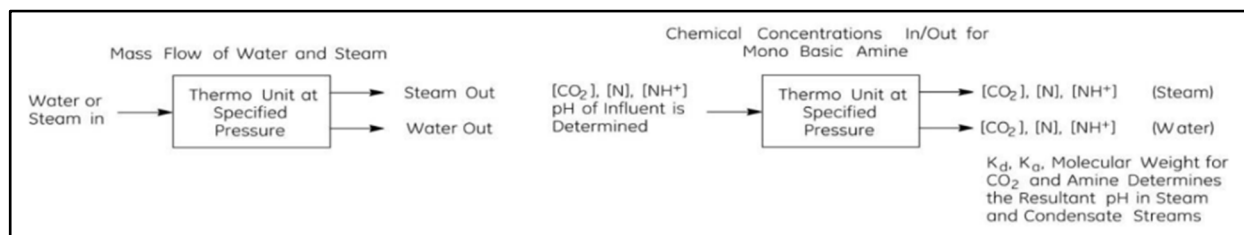
The CMS software can be used to simulate the effects of various chemicals, including contaminants and treatment chemicals, in steam generators. Users of the tool can build models to analyze a variety of different types of systems. CMS models consider not only the equilibrium and volatility characteristics of various treatment chemicals and common contaminants, but also solve the steady state mass balances for water and individual chemical components.

The CMS user can generate system-specific models by linking together a set of phase separation units called “thermo units.” Steam and water are assumed to be at thermodynamic equilibrium in these “thermo units” which include boilers, deaerators, flash tanks, and condensers. CMS allows the user to mix various streams, split streams, incorporate recycle loops and to specify pressures, temperatures, flow rates or chemical compositions. Once a solution to a particular model has been computed, CMS provides a report that can detail the chemistry of each stream in that model. Some of the output variables are:

- pH at 25°C
- pH at system operating temperature
- Flow rate of steam or water
- Individual chemical concentrations (based on weight or moles)
- Conductivity at 25°C
- Alkalinities (both P and M)
- Ionic species present (e.g., carbonic acid, bicarbonate, and carbonate)

Figure 1 shows how a single thermo unit works. Essentially, the program solves for the water balance around the thermo unit, then performs volatility, mass balance, and equilibrium calculations to determine the chemistry of the output streams. It is assumed for each thermo unit that water is saturated at the specified temperature (or pressure), and that chemical concentrations are at equilibrium conditions.

Figure 1 - Illustration of a “thermo unit” in CMS



To understand how the CMS program works for a single thermo unit, consider a single flash tank with carbonic acid and one neutralizing amine in the flash tank feed. Figure 2 shows that there are ten different equations that must be solved simultaneously in this example. One can imagine

Figure 2 - Equations for a single thermo unit, including one amine and carbonic acid

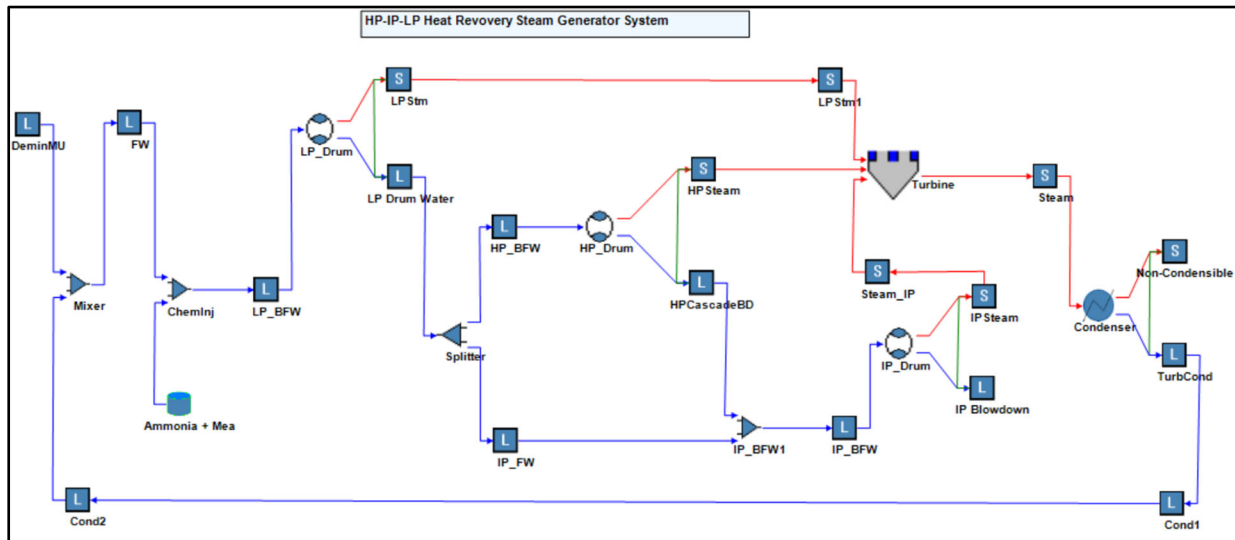
$$\begin{array}{l}
 1. \quad [\text{H}_2\text{CO}_3] = \frac{[\text{Total_CO}_2 \text{ liq}] * [\text{H}^+]^2}{([\text{H}^+]^2 + \text{KC}_1 * [\text{H}^+] + \text{KC}_1 * \text{KC}_2)} \\
 2. \quad [\text{HCO}_3^-] = \frac{[\text{Total_CO}_2 \text{ liq}] * \text{KC}_1 * [\text{H}^+]}{([\text{H}^+]^2 + \text{KC}_1 * [\text{H}^+] + \text{KC}_1 * \text{KC}_2)} \\
 3. \quad [\text{CO}_3^{2-}] = \frac{[\text{Total_CO}_2 \text{ liq}] * \text{KC}_1 * \text{KC}_2}{([\text{H}^+]^2 + \text{KC}_1 * [\text{H}^+] + \text{KC}_1 * \text{KC}_2)} \\
 4. \quad [\text{N}] = \frac{[\text{Total_N liq}] * \text{KN}_1 * \text{KN}_2}{(\text{KN}_1 * \text{KN}_2 + \text{KN}_1 * [\text{H}^+] + [\text{H}^+]^2)} \\
 5. \quad [\text{N}^+] = \frac{[\text{Total_N liq}] * [\text{H}^+] * \text{KN}_1}{(\text{KN}_1 * \text{KN}_2 + \text{KN}_1 * [\text{H}^+] + [\text{H}^+]^2)} \\
 6. \quad [\text{N}^{2+}] = \frac{[\text{Total_N liq}] * [\text{H}^+]^2}{(\text{KN}_1 * \text{KN}_2 + \text{KN}_1 * [\text{H}^+] + [\text{H}^+]^2)} \\
 7. \quad K_w = [\text{H}^+] * [\text{OH}^-] \\
 8. \quad K_d [\text{CO}_2] = \frac{[\text{Total_CO}_2 \text{ stm}]}{[\text{H}_2\text{CO}_3]} \\
 9. \quad K_d [\text{N}] = \frac{[\text{Total_N stm}]}{[\text{N}]} \\
 10. \quad [\text{H}^+] - [\text{OH}^-] - [\text{HCO}_3^-] - 2 * [\text{CO}_3^{2-}] + [\text{N}^+] + 2 * [\text{N}^{2+}] = 0
 \end{array}$$

that when thermo units are linked together, and when more chemicals are added to a CMS model, the number of equations that need to be solved simultaneously can become nearly impossible to solve by hand. Therefore, a computerized tool is essential to enable complex systems to be modeled accurately. If the model being developed is complex and includes recycle streams, an iterative approach to generating a solution is required. The CMS software tool includes a utility to streamline the iterative process, so that solutions can be generated very quickly, usually within a few minutes, depending on the complexity of the model.

One of the unique features of the CMS software is that the volatilities of each component, particularly the neutralizing amines, carbon dioxide, and organic acids, are not assumed to be fixed values. Unlike some other programs that have been used in industry, CMS corrects the volatilities of each component for both pH and temperature. This is important because volatilities can change significantly over the pH and temperature ranges used in CMS models. Another key feature of the tool is an easy-to-use graphical interface that allows users to build simple or complex models that are specific to the system being evaluated. For example, Figure 3 shows a CMS model that was developed to simulate the water and steam chemistries in a 3-drum heat recovery steam generator (HRSG) system with blowdown being cascaded from the HP steam drum to the IP steam drum. This model enabled the user to determine the pH and specific conductance values at each point in the system when given a specific dosage of treatment chemical. The user was also able to determine how ammonia or neutralizing amines would distribute throughout the entire steam condensate system.

While the CMS software has been extremely useful in optimizing condensate system treatments, it has also become an invaluable tool in helping to troubleshoot boiler systems that are

Figure 3 - Example CMS model for a 3-drum HRSG with cascade blowdown from HP to IP steam drums



experiencing contamination or other issues. In particular, the tool has been very effective in troubleshooting boiler systems that are experiencing demineralizer performance issues (e.g., sodium slippage), raw water intrusion, and organic contamination. In these cases, the CMS tool enables the user to determine chemical treatment or operational strategies to counter the effects of this contamination.

Another application of CMS is to provide proper control limit guidance when amines or ammonia are used with congruent phosphate or with phosphate treatment programs commonly applied in the power generation industry. In this situation, failure to make the proper corrections can result in boiler tube damage caused by under-deposit acidic corrosion. Recent trends in the industry have been to elevate feedwater pH well above 9.0 in order to reduce potential for flow-accelerated corrosion (FAC) in low pressure feedwater circuits. As feedwater pH is increased, the need to correct the boiler water pH and phosphate control limits becomes much more important. This is because ammonia and neutralizing amines affect the pH of the boiler water, but do not provide enough buffering under boiler tube deposits to counteract the effects of acidic components such as chloride. Published phosphate and pH control charts do not account for the presence of ammonia or neutralizing amines. Using these published charts without the proper corrections, can lead to boiler tube damage or failure due to acidic under-deposit corrosion.

The next sections discuss several case studies that demonstrate how the CMS tool can be used to solve problems that are not primarily focused on condensate system corrosion protection.

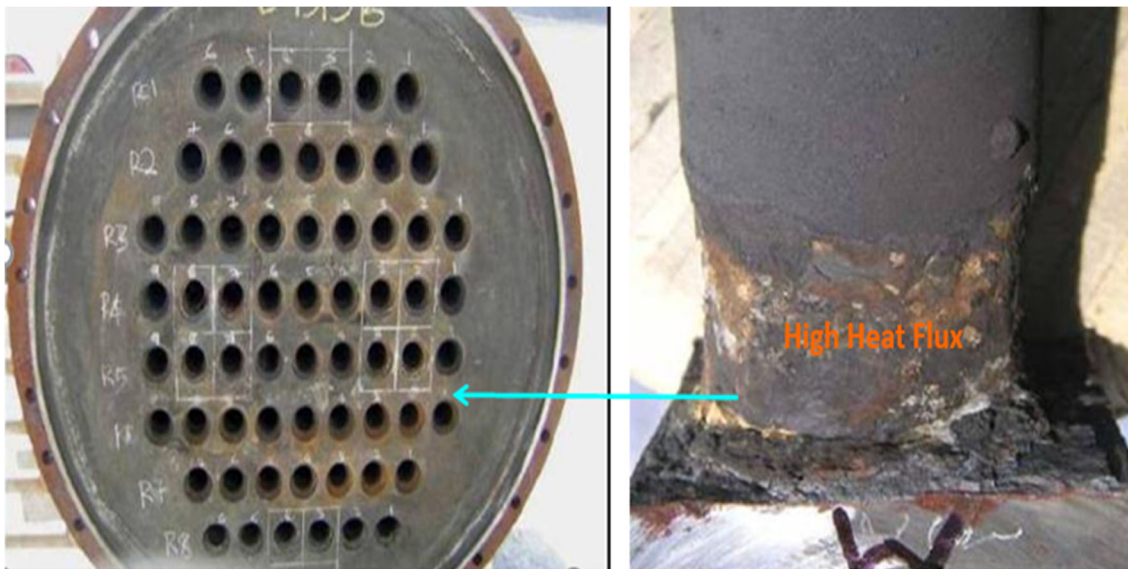
CASE STUDIES

ETHYLENE PLANT TLE – An ethylene plant transfer line exchanger (TLE) operating at 105 barg (1,508 psig) and about 50 cycles of concentration was being treated using a Low-Phosphate Continuum program also known in industry as PC(L). Trisodium phosphate (Na_3PO_4 mole ratio of 3.0) was being applied to achieve a phosphate concentration in the boiler water of about 1

ppm (expressed as PO_4). A neutralizing amine blend containing cyclohexylamine and morpholine was being used to control boiler feedwater and steam pH to 9.0 (measured at 25°C).

To minimize undesirable side-reactions in the effluent from the pyrolysis furnace, the purpose of the TLE is to quench the cracked hydrocarbon gas from a temperature of roughly 850°C (1,500°F) down to between 250°C and 400°C (480°F to 750°F). Figure 4 shows the localized corrosion damage that was observed in one section of the TLE. Metallurgical analysis confirmed that the failure was caused by a high concentration of mineral acid resulting from high temperatures, excessive heat flux, and boiler feedwater contamination.

Figure 4 - Corrosion damage in a high heat flux zone of the TLE



While the PC(L) treatment program is designed to minimize phosphate concentration, and therefore reduce potential for phosphate hideout, the downside of operating at lower phosphate concentrations is that there is less buffering agent present to counteract acidic contaminants. This is especially true in areas where there are concentration cells, regardless of whether these concentration cells are caused by excessive heat flux or by porous iron oxide deposits on heat transfer surfaces.

As a result of the TLE failures, plant operating personnel wanted to better understand how the chemical treatment program would perform with higher concentrations of phosphate in the boiler water, and with varying concentrations of chloride in the boiler feedwater.

The CMS software was used to model the system with chloride contamination levels up to 50 ppb in the boiler feedwater. Chloride will form hydrochloric acid (HCl) in the boiler water and will tend to depress the boiler water pH. The CMS tool was used in this case, not only to model the boiler water pH at 50 cycles of concentration, but also the pH of a concentration cell which was assumed to concentrate the feedwater by 1,000 times. Figure 5 shows how the actual model was constructed using the CMS graphical interface. Figure 6 shows the effect of chloride contamination on the bulk boiler water pH using this model.

Figure 5 - Concentration cell modeling using CMS

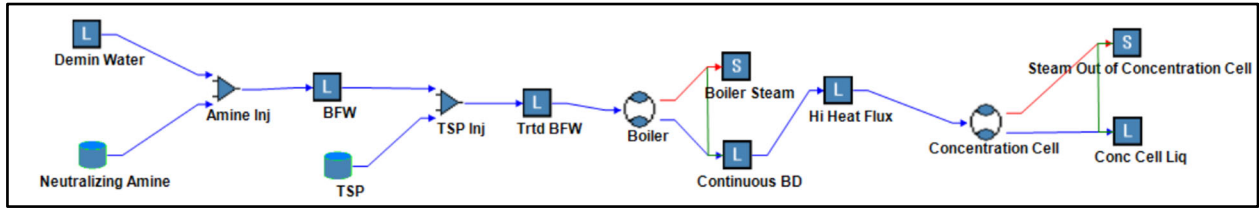


Figure 6 - Effect of feedwater chloride contamination on bulk boiler water pH measured at 25°C

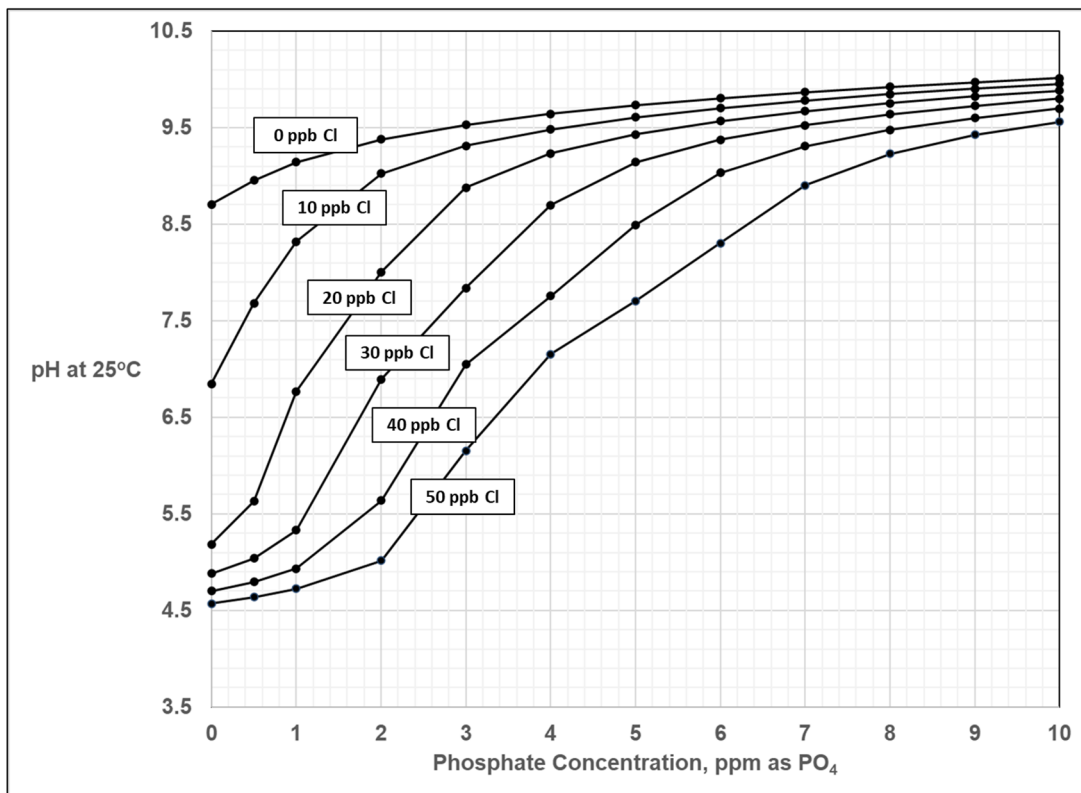


Figure 6 shows that for the TLE operating at 50 cycles of concentration, and with the neutralizing amine blend being used to adjust feedwater pH to 9.0, small amounts of feedwater contamination can depress the boiler water pH significantly. At 1 ppm PO₄ in the bulk boiler water, chloride concentrations as low as 10 ppb would reduce bulk boiler water pH measurements significantly. Furthermore, the graph shows that the pH depression resulting from chloride contamination becomes less pronounced as the phosphate concentration is increased.

Table 1 shows the pH data in the concentration cell as a function of bulk boiler water phosphate concentration with varying levels of chloride in the boiler feedwater. The red values are highlighted because they are below neutral pH, making them acidic and potentially damaging to the boiler tube metal.

Table 1 - pH at 25°C in concentration cell (CR=1,000) with varying levels of feedwater chloride

ppm PO ₄ in Bulk Boiler Water	ppb Chloride in Boiler Feedwater						
	0	5	10	20	30	40	50
0	5.87	4.07	3.79	3.51	3.34	3.23	3.13
0.5	7.88	7.40	4.70	3.83	3.54	3.37	3.25
1	8.17	8.00	7.69	4.56	3.88	3.58	3.40
2	8.45	8.37	8.27	7.97	6.21	4.45	3.94
3	8.61	8.56	8.50	8.35	8.12	7.63	5.06
4	8.72	8.68	8.64	8.54	8.41	8.22	7.91
5	8.81	8.78	8.74	8.66	8.57	8.46	8.30
6	8.88	8.85	8.82	8.76	8.69	8.60	8.50
7	8.93	8.91	8.89	8.83	8.77	8.71	8.63
8	8.98	8.96	8.94	8.89	8.84	8.79	8.72
9	9.03	9.01	8.99	8.95	8.90	8.85	8.80
10	9.06	9.05	9.03	8.99	8.95	8.91	8.86

As shown in Table 1, higher levels of phosphate in the bulk boiler water will certainly provide a more effective buffer against chloride contamination by keeping the pH of the boiler water in the concentration cell elevated above the neutral pH value. The question then can be posed which is, “How much chloride in the boiler feedwater can be tolerated as a function of boiler water phosphate concentration?” The CMS tool can help answer this question as well. By using a “goal seek” feature within CMS, the model can be run to determine the amount of feedwater contamination that would achieve a neutral pH within the concentration cell at varying levels of phosphate in the boiler water. Table 2 provides the results of these calculations.

Table 2 - Feedwater chloride concentration to achieve neutral pH in the concentration cell

ppm PO ₄ in Boiler Water	ppb Cl in Feedwater
0	0.2
0.5	6.2
1	12.2
2	24.4
3	36.5
4	48.6
5	60.7
6	72.8
7	84.9
8	97.0

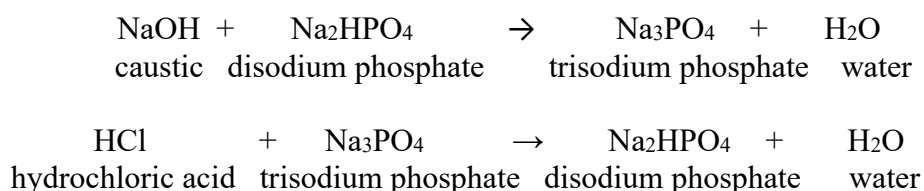
Table 2 shows that the more trisodium phosphate that is present in the boiler water, the more buffering capacity there is, and the more chloride contamination can be tolerated. The relationship is a perfectly straight line.

Overall, in this case study, the CMS tool provided useful site-specific information to the plant operator. The results of the CMS modeling confirmed that higher levels of phosphate in the boiler water can substantially increase the buffering capacity and protect the TLE more effectively from corrosion caused by chloride contamination, especially when concentration cells form that are caused by excessive heat flux (i.e., localized boiling) or by boiler water concentrating under porous deposits. Ultimately, even though the CMS data illustrated the potential benefits of applying more phosphate, the decision to raise the phosphate concentration is more complicated. For example, as more phosphate is applied, steam purity may suffer. Furthermore, the application of more phosphate can increase potential for phosphate hideout which can also lead to corrosion damage. Like with many engineering problems, there is a balance of risks and benefits in this case. However, with the information provided by the CMS tool, the plant operator has much more information available with which to assess the best path forward.

AMMONIA PLANT BOILER CONGRUENT PHOSPHATE CONTROL - A Kellogg ammonia plant was experiencing frequent failures in their high-pressure waste heat boilers (101CA/101CB) that operated at 103 barg (1,500 psig). The tube failures led to unscheduled plant shutdowns and resulted in substantial production losses.

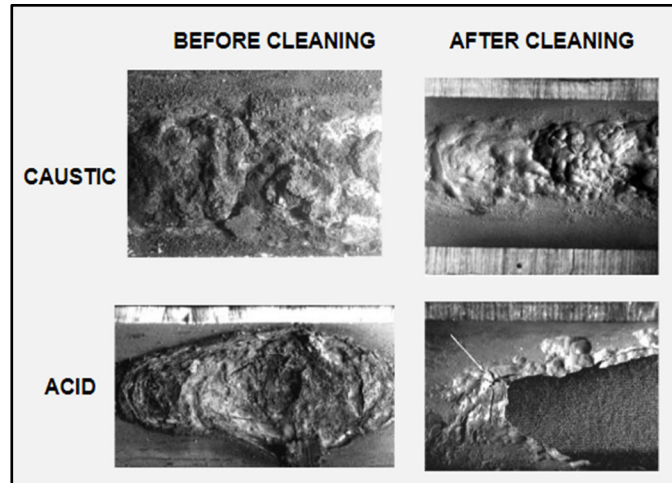
The ammonia plant waste heat boilers function to cool process gas from the secondary reformer from about 1,000°C (1,830°F) down to about 450°C (840°F). Due to the very high temperatures involved, porous deposits of iron form concentration cells which can concentrate either acid or caustic, leading to localized corrosion damage if boiler water chemistry is not properly maintained. The Congruent Phosphate chemical treatment program was designed to address these corrosion issues and has been widely accepted in the ammonia industry. The Congruent Phosphate treatment program has performed well in these applications when applied and controlled properly.

Like the Phosphate Continuum program discussed in the previous case study, Congruent Phosphate programs utilize phosphate to buffer the boiler water under deposits. The chemical reactions are:



The goal of the Congruent Phosphate program is to maintain the pH of the water under the deposits in a non-corrosive range, so that localized corrosion damage and tube failures do not occur. Figure 7 shows examples of under-deposit corrosion that can occur if there is feedwater contamination from sodium or chloride and if the boiler water chemistry is not properly maintained. The photos show what the tubes looked like before and after cleaning. Both the acidic and caustic corrosion mechanisms can result in significant localized corrosion damage, poor operating reliability, and lost production.

Figure 7 - Examples of acidic and caustic under-deposit corrosion in a boiler tube



To reduce iron transport into these waste heat boilers from the feedwater circuit, there has been a trend in the ammonia industry to use neutralizing amines to elevate the pH of the boiler feedwater to values well above 9.0. Different neutralizing amine formulations are used to accomplish this. However, the use of ethanolamine (MEA) has become more commonplace, as it has a high basicity constant which helps to economically elevate feedwater pH. Due to its low volatility, MEA tends to concentrate in the liquid phase and raises the boiler water pH. While MEA does elevate the pH of the bulk boiler water when tested at 25°C, it provides little buffering effect at boiler temperatures.

The standard Congruent Phosphate control diagram is shown on Figure 8. This diagram assumes that the system contains no ammonia or neutralizing amines. The relationship between boiler water pH measured at 25°C and phosphate is assumed to be based only on the concentrations of sodium and phosphate. Control is achieved by dosing phosphate chemicals containing the proper sodium and phosphate ratio or caustic (if needed), and by adjusting the boiler's continuous blowdown flow rate. For many years, the plant had been using this standard, uncorrected control diagram, targeting a phosphate concentration in the boiler water between 4 and 8 ppm. Figure 9 shows the actual control diagram being used by the plant. This diagram was not corrected for the presence of neutralizing amine.

The plant was feeding a neutralizing amine formulation containing MEA to achieve a boiler feedwater pH of 9.2. The CMS tool was used to correct the control box for the presence of the neutralizing amine in the boiler water. Figure 10 shows the corrected box, with the corrected box being highlighted in green. By observing Figure 10, it becomes clear that much of the uncorrected box lies in a region where acid phosphate corrosion can occur.

The plant had been dosing their boiler chemicals manually through a day tank and were adjusting chemical dosages twice per day. This resulted in wide swings in boiler chemistry, as the adjustments were too frequent, sometimes not necessary, and often too aggressive. Additionally, the plant was targeting the wrong control box. Control that was achieved during this time was poor and was correct less than 50% of the time as shown on Figure 11. This left the plant open to

Figure 8 - Congruent Phosphate control chart

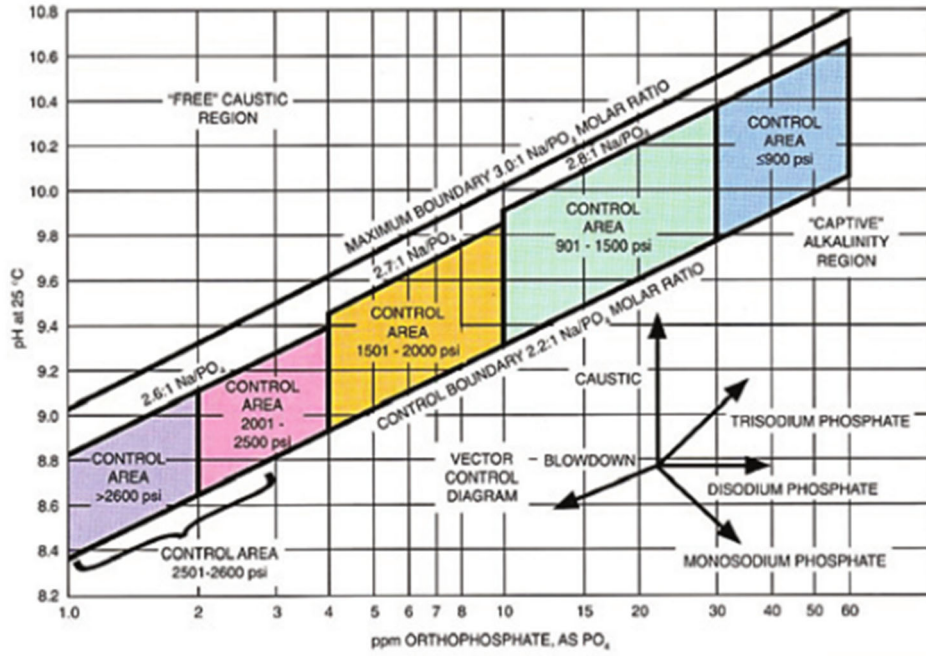


Figure 9 - Congruent Phosphate control diagram for ammonia plant - not corrected for neutralizing amine

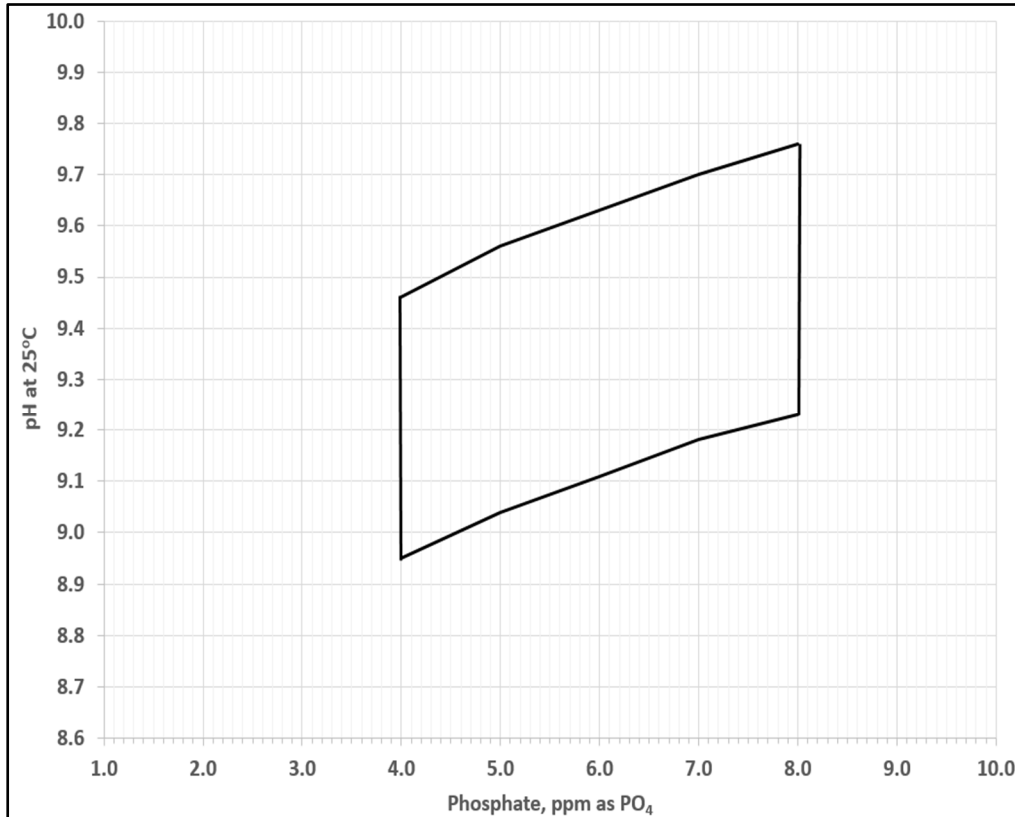


Figure 10 - Congruent Phosphate control box - corrected for neutralizing amine

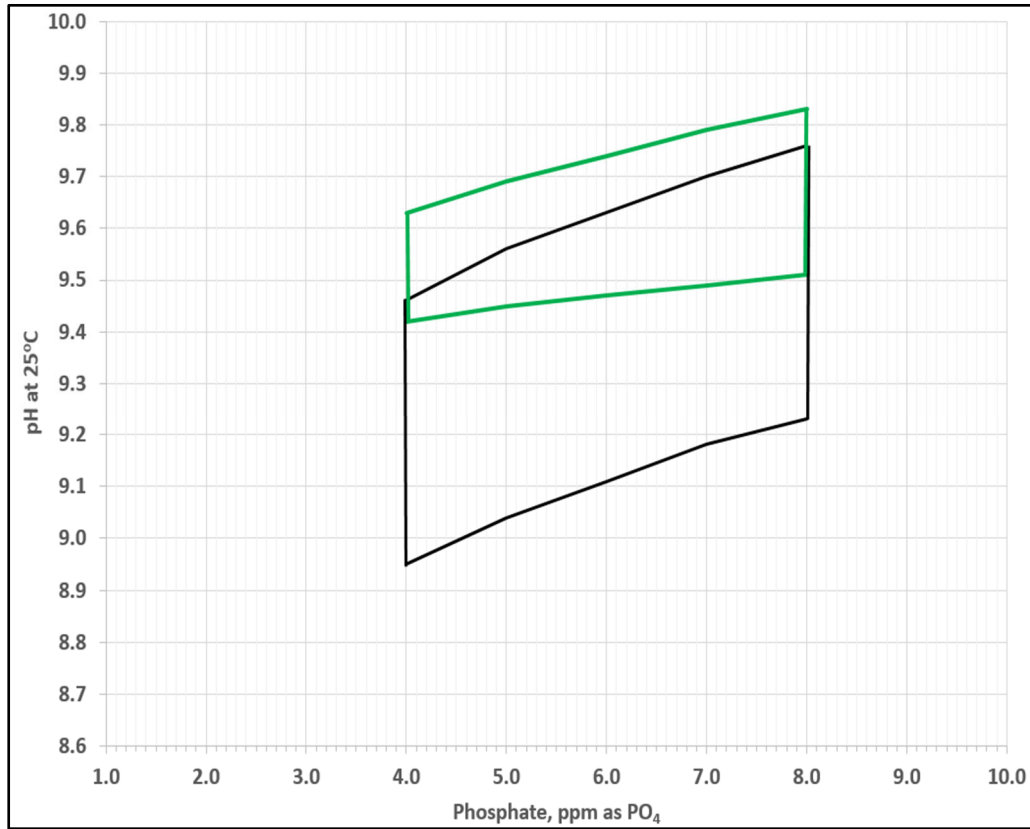
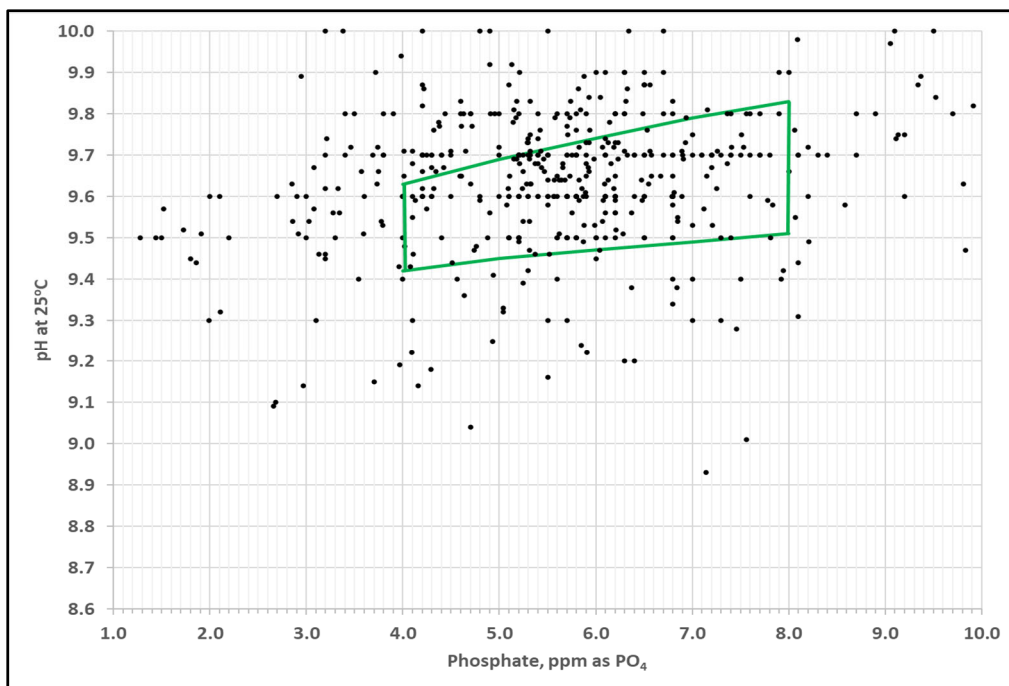
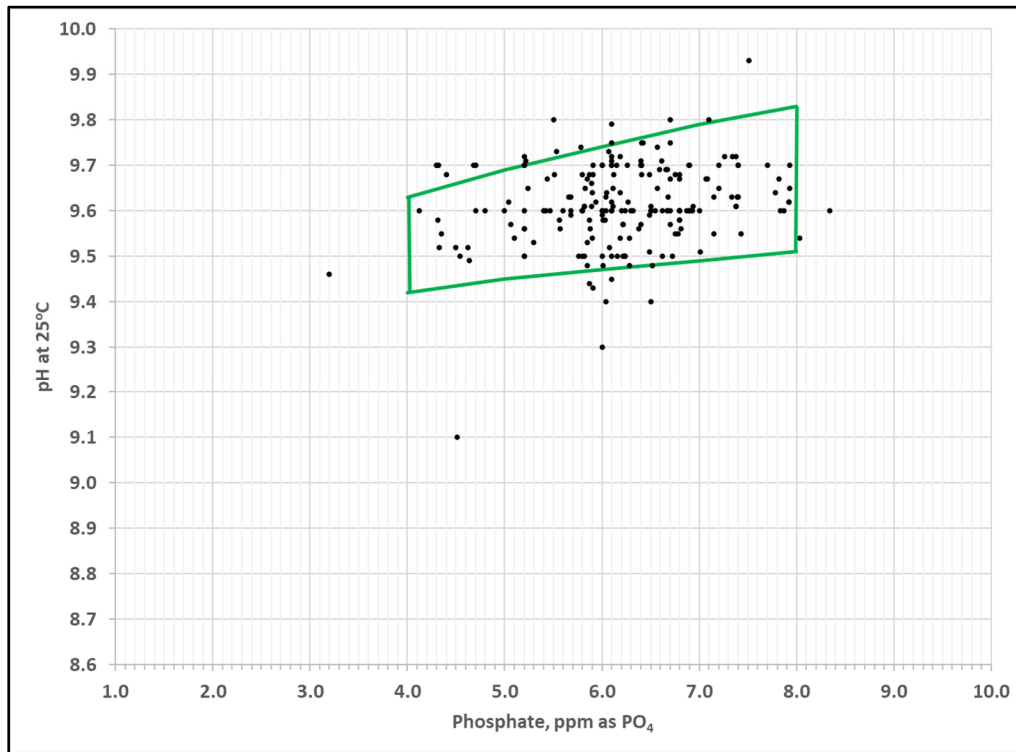


Figure 11 - Congruent Phosphate control over 2 years with manual chemical dosing



both acidic and caustic corrosion, as some points were above the corrected box, and many were below. Plant personnel realized that another approach was needed and have since installed an automated chemical feed and control system. This system has improved the boiler water chemistry control dramatically as observed in Figure 12.

Figure 12 - Congruent Phosphate control over 1-year period using automated chemical feed and control system



This plant had been operated for a long period of time using a set of boiler water pH and phosphate control limits that were not correct. This led to frequent boiler tube failures (about 2 per year) that caused unscheduled plant outages, high maintenance and repair costs, and lost ammonia production. Installation of the automated chemical feed and control system and using the CMS tool to develop the correct pH and phosphate control limits have led to a considerable improvement in plant reliability with no water-treatment related outages for more than a year.

POWER PLANT HEAT RECOVERY STEAM GENERATOR - A power-producing facility burning natural gas operated a three-drum heat recovery steam generator (HRSG). The system included a feed forward LP drum (FFLP) that was treated with a neutralizing amine formulation containing cyclohexylamine and morpholine. By injecting the neutralizing amine, the low-pressure (LP) drum water pH was maintained at 9.6 to minimize potential for flow-accelerated corrosion in the feedwater circuit and in the LP evaporator. Pressures for the system were 100, 600, and 1,900 psig for the LP, intermediate-pressure (IP), and high-pressure (HP) drums respectively.

The plant operating personnel were concerned about pH depression that was being experienced in the IP drum. The HP drum water pH was consistently maintained at 9.3 with a phosphate concentration of about 5 ppm as PO₄. However, the IP drum water often fell below a pH of 9.0 which was outside of the normal operating targets specified for the plant. The plant operations team wanted guidance on how to address the low pH in the IP drum.

Water testing revealed that there were significant concentrations of acetic acid in the boiler water resulting from the decomposition of the neutralizing amine components being fed to the system. These organic acids concentrated in the IP drum due to the blowdown water being cascaded from the HP to the IP drum, as well as from the organic acid being recycled throughout the system. The concentration of acetic acid in the IP drum was found to be 8.6 ppm.

The HRSG cycle was simulated using the CMS software based on a mass balance as shown on Table 3. The actual CMS model structure used in this study was the same as the 3-drum HRSG model depicted previously on Figure 3.

Table 3 - Mass balance used for HRSG system CMS modeling

		lbs/hr	
		In	Out
Condenser Hotwell	Fresh demineralized makeup water	40,758	
	Unpolished condensate return	959,242	
	Total	1,000,000	1,000,000
LP Drum	Flow from hotwell to LP drum	1,000,000	
	LP steam production		18,676
	LP water to HP/IP drums		981,324
	Total	1,000,000	1,000,000
IP Drum	Feedwater from LP Drum	85,723	
	Cascade from HP drum to IP drum	24,878	
	IP steam production		99,541
	IP blowdown		11,060
	Total	110,601	110,601
HP Drum	Feedwater from LP drum to HP drum	870,723	
	HP steam production		845,845
	HP blowdown to IP drum		24,878
	Total	870,723	870,723
Surface Condenser	Total plant steam to condenser	964,062	
	Loss from noncondensable removal		4,820
	Condensate to hotwell		959,242
	Total	964,062	964,062

To determine an immediate solution to the low pH issue in the IP drum, the CMS tool was used to calculate the amount of caustic that would need to be injected into the IP drum to maintain the drum water pH at 9.30. As a first step, the system was simulated to determine the concentrations of neutralizing amine in the IP drum water. These concentrations were also confirmed via specific amine analysis. The chemistry of the IP drum water was established as shown in Figure 13. Once this task was completed, the CMS “titration” function was used to compute how much sodium hydroxide was needed to elevate the IP drum water pH. Like a chemistry titration done in the laboratory, this function of CMS allows the user to calculate the amount of acid or base addition needed to obtain a specific pH.

The modeling showed that a dosage of about 200 ml per day of 50% sodium hydroxide would bring the IP drum water pH up to 9.3. This was a short-term solution for the plant, as it was not desirable for the operations team to handle and dose concentrated caustic to the IP feed system day tank. The plant considered two long-term solution options. One of these options was to apply a liquid phosphate product with a small amount of extra caustic to overcome the organic acids in the IP drum water. Another possible solution was to select a different volatile alkali product to replace the existing neutralizing amine product. This product would consist of ammonia with a small fraction of low-volatility neutralizing amine to protect initial condensation points. By applying such a product, no change would be needed to the boiler phosphate products, and there would be significantly less organic acid contamination from the decomposition of neutralizing amines in the cycle. By reviewing CMS simulations, the plant chose this course of action.

Figure 13 - IP drum water chemistry, flow, and operating pressure from CMS

Parameters	IP Drum Water
Flow	11,488.363
Pressure, psig	600.000
pH	8.963
Morph, ppm	11.917
Cyclo, ppm	0.566
Na, ppm	7.892
PO4, ppm	11.040
Def	0.000
Conductivity, μ S/cm	32.581
Acetate, ppm	8.617
CO2, ppm	
Cl, ppm	

SUMMARY

The examples presented in this paper illustrate the power of using a computerized software tool such as CMS to troubleshoot and optimize boiler water chemistry, and to select appropriate chemical formulations for boiler water, steam or condensate treatment. The examples also show that the CMS tool can be used to simulate conditions not only in the bulk boiler water, but also can also be used to model concentration cell conditions that occur underneath deposits or in high heat flux zones of a boiler. Without the CMS tool it would be difficult to understand the conditions that occur in these areas in relation to the bulk boiler water chemistry. As the CMS software continues to evolve, more applications for the program will be developed to help plant operators improve their strategies for chemical treatment, reduce operating costs, and improve overall plant reliability.

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