

Solus* AP

Advanced Boiler All-Polymer Internal Treatment Technology

A Discussion in Question and Answer Format

1. What is Solus AP boiler treatment technology?

Solus AP is the latest technological innovation in boiler scale control and internal treatment from GE Water & Process Technologies. This all-polymer technology is designed to meet the deposit control performance needs of modern low-to-intermediate pressure steam boilers (up to 900 psig) and is a cost effective, easy-to-use treatment in a stable, liquid formulation.

With Solus AP, operators can maintain cleaner, scale-free boiler internal heat transfer surfaces, especially under stressed conditions such as upsets which can result in high feedwater contaminant loading. This helps maintain design levels of heat transfer and fuel-to-steam efficiency. It also enhances boiler reliability and availability by reducing the potential for tube failures due to overheating, under-deposit corrosion, or restricted water circulation.

Solus AP is also designed with modern pretreatment systems in mind. With the widespread use of membrane-based, reverse osmosis pretreatment, iron corrosion products are frequently the dominant contaminant entering the boiler, versus hardness, which typically dominates systems receiving sodium zeolite softened make-up water.

As shown by the data that follows, Solus AP delivers improved control of iron oxide deposition versus standard polymers, as well as enhanced rejection of iron contaminant via the boiler blowdown. It also

provides outstanding control of hardness-based deposits and improved transport of magnesium hardness versus existing all-polymer technologies.

The Boiler Terpolymer (BTP) – the backbone of Solus AP

Solus AP is based on GE's patented Boiler Terpolymer (BTP), a "terpolymer," which consists of three chemically distinct polymer building blocks, called monomers. Each monomer in BTP, as well as the ratios of the monomers, is carefully selected to enhance overall performance.

BTP represents the evolution of GE boiler polymer technology, with several new structural features that enhance its performance. BTP provides measurable advantages in performance over existing all-polymer chemistries, notably improved iron oxide scale control and iron rejection to the blowdown, improved magnesium hardness transport, and superior stress tolerance under upset conditions. BTP can also effectively recover from hardness contaminant upsets.

2. Does Solus AP technology effectively control scale formation at the boiler heat transfer surface?

In the performance comparisons reviewed below, GE's Solus AP products were evaluated over a broad range of pressures and levels of feedwater contaminant stress. Testing was completed in licensed, research-scale steam boilers that are capable of



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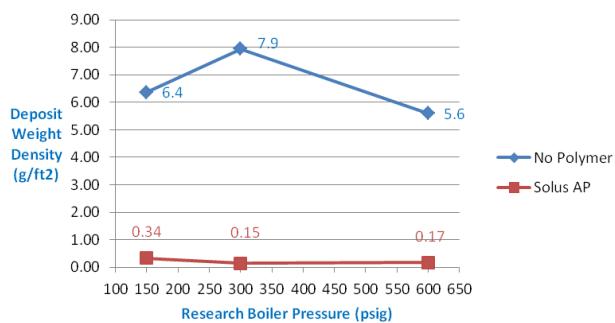
operation at steam pressures between 50 and 1450 psig (approximately 3 to 100 barg).

Excellent correlations have consistently been observed between the polymer deposit control and contaminant transport performance measured in these GE Research boilers versus actual operating boiler systems. Deposit weight density measurements were made at the steaming heat transfer surface, which are immersed electric resistance heat elements with discrete heat transfer surfaces. The steam pressure, blowdown rate, cycles of concentration, and feedwater contaminant matrix can be tightly controlled and replicated between runs to allow performance comparisons under identical conditions. In addition, contaminant transport performance can be evaluated by comparing feedwater and the blowdown levels of specific elements, typically calcium, magnesium, iron, and silica.

Deposit Control Performance

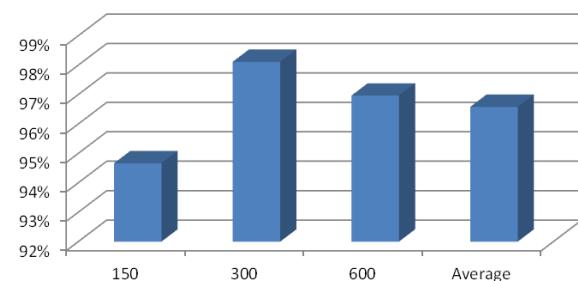
Figure 1A illustrates the performance of Solus AP versus an untreated control. Solus AP reduced deposition at the test boiling heat transfer surface over the pressure range of 150 to 600 psig when feedwaters contained high levels of hardness, iron, and silica contaminants.

Figure 1A - Deposition Rate at Heat Transfer Surface with Solus AP versus Untreated Control



As illustrated in Figure 1B, Solus AP reduced scale formation by at least 95 percent in all cases versus the untreated control. Figure 1C shows the actual test heat transfer surfaces as removed from a run at 300 psig with high levels of feedwater hardness, iron, and silica contaminant.

Figure 1B - % Deposit Inhibition provided by Solus AP over 150 to 600 psig



The untreated control in the upper part of Figure 1C clearly shows the high affinity of this mixed hardness/iron deposit for the boiling heat transfer surface. This is represented by the discrete, heated band in the center of the probe where the heavy white deposit appears. Insulating scale deposits at the evaporative heat transfer surface can severely restrict heat transfer efficiency and can result in tube failures due to overheating damage to the carbon steel. It also provides sites for under-deposit corrosion mechanisms by concentrating potentially corrosive contaminants such as chloride, sulphate, and hydroxide due to evaporative cycling under porous deposits.

The lower photograph in Figure 1C is of test probes removed at 300 psig under identical conditions of feedwater contamination, except that the feedwater contained the recommended level of Solus AP. As shown in Figure 1B, Solus AP provided 98 percent deposit inhibition - in essence a clean, deposit-free heat transfer surface.

Figure 1C - Research Boiler Test Heat Transfer Surface Untreated control and Solus AP treatment at 300 psig

Untreated control from 300 psig test after 4-day test with hardness-dominated feedwater contaminant. Note that white hardness-based deposit is on discrete, electrically heated steaming heat transfer surface and largely absent from non-heat transfer surfaces.



Solus AP treated probe from same 300 psig, 4-day test condition with same hardness-dominated feedwater contaminant as untreated control. Note that steaming heat transfer "band" is clearly visible but free of scale.

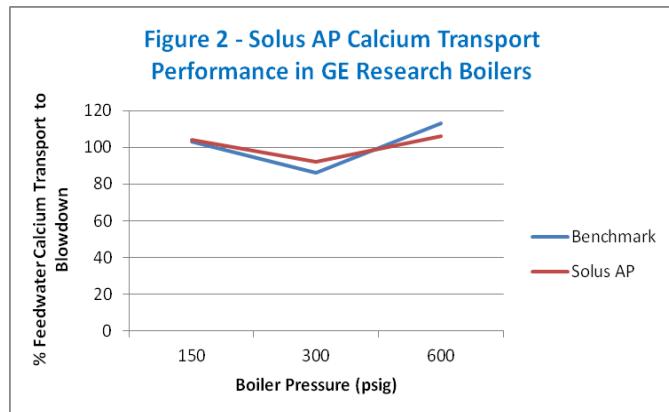


3. Was Solus AP technology effective in transporting feedwater contaminant through the boiler?

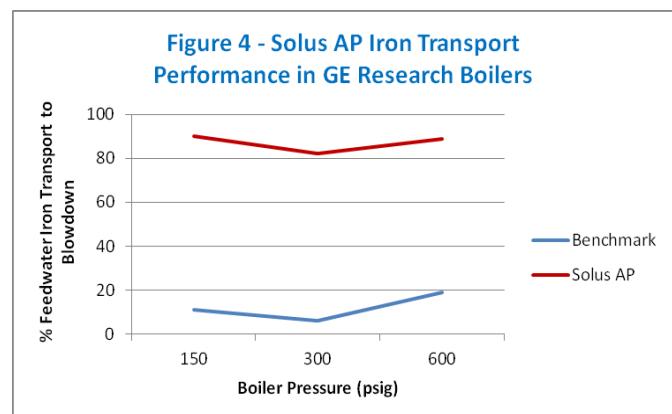
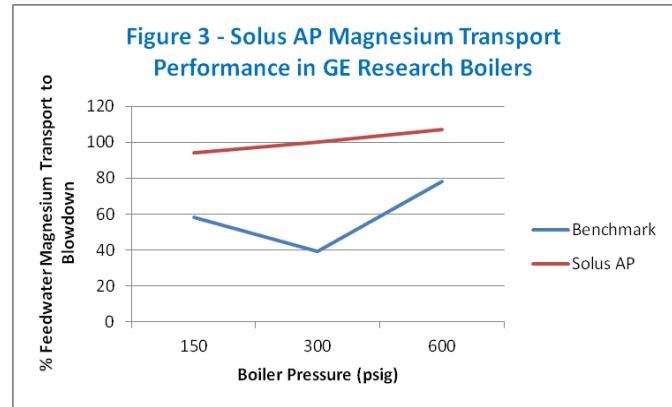
Contaminant Rejection to Blowdown

Figures 2, 3 and 4 summarize the feedwater contaminant transport (or contaminant rejection to blowdown) with Solus AP versus a standard industry benchmark polymer.

As shown in Figure 2, both polymers effectively transported calcium contaminant through the boilers and rejected it at close to 100 percent efficiency to the blowdown. It should be noted that both polymers were applied at their recommended and optimized dosages, and in no case did the dosage level of the BTP in Solus AP exceed that of the benchmark.



Figures 3 and 4 show that magnesium and iron transport were dramatically improved with Solus AP versus the benchmark. This translates to cleaner boilers and reduced accumulation of magnesium and iron-based sludge deposits, both on the evaporative heat transfer surfaces and on the lower temperature, non-evaporative surfaces. Excessive accumulation of sludge can negatively impact water circulation and supply to generating tubes, and porous deposits may also provide sites for under-deposit corrosion mechanisms, such as acid attack or caustic corrosion.

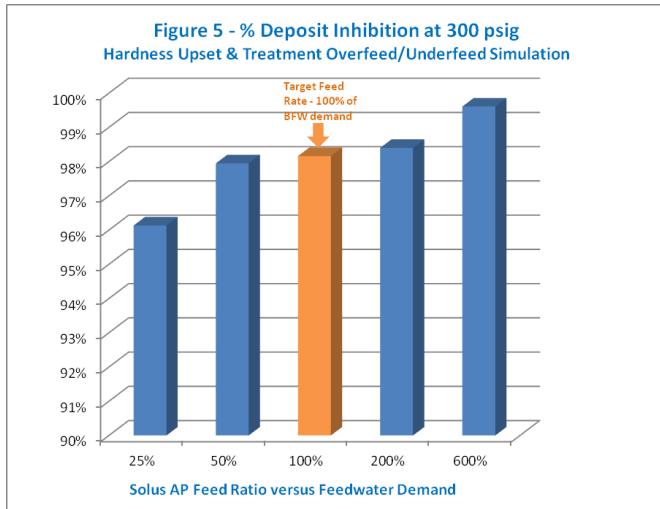


4. Does Solus AP provide forgiveness regarding under dosing and over-dosing of the polymer, as well as during feedwater upsets?

Flexibility & Forgiveness

Deposit control treatments must provide both flexibility and forgiveness under upset conditions, as well during periods of temporary treatment underfeed or overfeed. Figure 5 illustrates the tolerance of Solus AP to temporary underfeed and overfeed at 300 psig in a mixed hardness/iron/silica feedwater contaminant system.

The Solus AP terpolymer shows outstanding levels of forgiveness, maintaining very high levels of deposit inhibition even when at only 25 percent of the recommended polymer dosage versus the incoming feedwater contaminant. This is a very important safety factor against temporary or sustained feedwater upsets and corrosion and illustrates how Solus AP performs under high levels of contaminant stress when performance is required to prevent damaging levels of deposition.



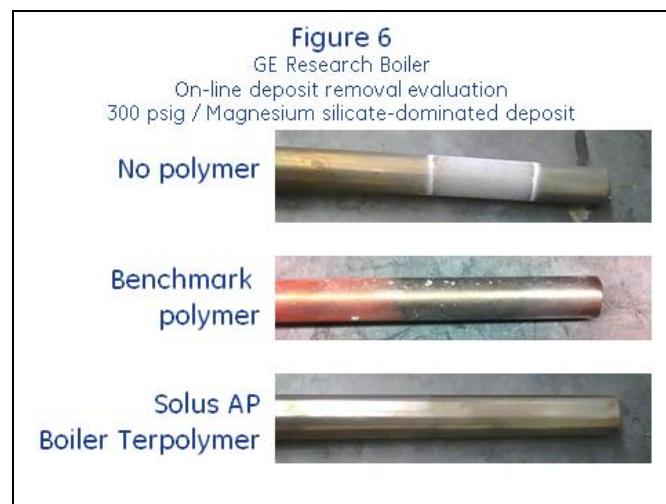
Solus AP maintained excellent deposit control performance even at two to six times feedwater demand and showed no tendency for polymer related fouling, which was an issue with some early all-polymer chemistries.

5. Can a Solus AP program assist with recovery from feedwater upsets?

An important and practical aspect in the performance of an internal treatment program designed for low-to-intermediate pressure boilers related to the ability to handle feedwater upsets is recovery from hardness deposition. A set of evaluations were performed to evaluate the ability of Solus AP to remove a freshly precipitated hardness-dominated deposit. In this case, the deposit composition was primarily magnesium silicate.

To simulate a feedwater upset event, a synthetic feedwater dominated by high levels of magnesium and silica contaminant and lower levels of calcium and iron contaminant was fed to the GE Research boiler for 72 hours with no internal treatment fed during this time. As shown in the upper photo in Figure 6, the test heat transfer surface developed a relatively heavy white deposit with a three-day deposit weight density of 2.6 g/ft². Deposit analysis confirmed that the composition was dominated as expected by magnesium silicate with minor amounts of calcium and iron.

As shown in Figure 6, when Solus AP was applied at higher than maintenance levels, the deposit was rapidly removed from the heat transfer surface. The previously mentioned benchmark polymer was applied at the same levels, and as shown, deposit removal was incomplete.



6. How well does Solus AP performance translate to the field?

The field evaluation pictured in Figures 7 and 8 was performed in a D-type watertube package boiler operating at 170 psig and receiving deaerated feedwater comprised of a combination of 20 percent softened municipal make-up water and 80 percent returned condensate.

From Fall 2011 to Fall 2012, the boiler was treated with the benchmark all-polymer technology referenced above. The municipal make-up in this case contained orthophosphate, which is added for corrosion control. This results in several parts-per-million of orthophosphate in the boiler water.

Inspection photos from the fall 2012 (Benchmark 2 polymer) and fall 2013 (Solus AP) inspections are shown in Figures 7 and 8, respectively. The distinguishing feature of the Fall 2013 inspection on the Solus AP program is that the white hardness-dominated deposit that was clearly visible on the steam drum and tube surfaces in the 2012 inspection was essentially removed completely.

Figure 7
170 psig D-Type Watertube Boiler
August 2012 Inspection
Benchmark Polymer 2 All-Polymer Program



Figure 9 – Solus AP Contaminant Transport Performance in Northeast University Boiler

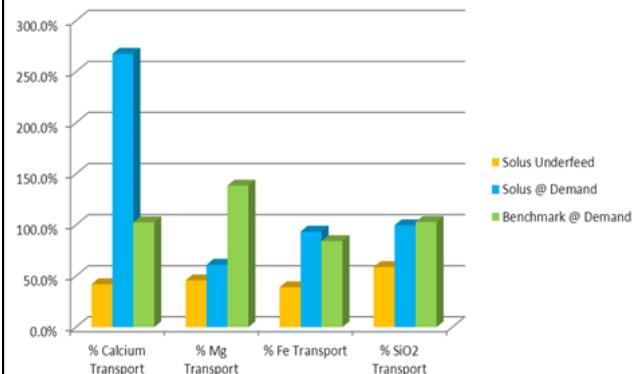
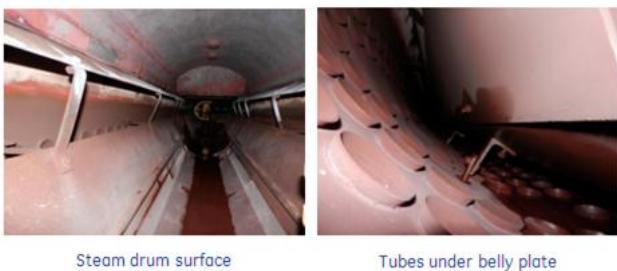


Figure 8
170 psig D-Type Watertube Boiler
August 2013 Inspection
One year on Solus AP All-Polymer Program



Heat Recovery Steam Generator Trial

The transport data summarized in Figure 9 is from a Solus AP trial in a simple cycle heat recovery steam generator at a university in the Northeast US. This unit received a combination of softened make-up and zeolite-polished condensate as feedwater. From late 2012 through early 2013, the main condensate return line was out-of-service for excavation and repair. With the loss of campus condensate, the make-up capacity of the softener system was severely challenged, especially during the winter and late spring periods of high steam demand.

Hardness levels in the feedwater during this period were elevated and highly variable, averaging approximately 3 ppm, but with frequent excursions between 5 and 30 ppm (as CaCO_3). This intermittent and highly variable pattern of hardness contamination resulted in hardness scale formation in the steam generator.

Interestingly, the hardness excursions coincided with the initiation of the Solus AP trial and temporarily resulted in a significant underfeed of treatment. As shown in Figure 9, during this underfeed period, with the Solus AP treatment fed at less than 10 percent of feedwater demand due to the intermittent hardness excursions, contaminant rejection levels were maintained in the 40 to 50 percent range for hardness, iron, and silica.

Once the condensate return line was repaired and condensate polisher capacity restored, the Solus AP dosage level was maintained at feedwater demand per the blue bars in Figure 9. This resulted in a dramatic increase in contaminant rejection rates.

Calcium rejection, measured for the period after restoration of the condensate return, has been maintained at above 250 percent for more than six weeks. This is a reflection of BTP's dramatic effect on removing the calcium carbonate-dominated deposit formed during the upset period. The monitoring of this application continues, but the results to date with Solus AP have been very encouraging.

7. Is Solus AP compatible with boiler feedwater system alloys?

All-polymer programs are designed to be fed to the boiler feedwater for optimum performance. This allows the polymer to complex soluble hardness contaminant prior to entry into the boiler and initiate adsorption and conditioning of particulates, in particular iron oxide corrosion products. It is important that the polymer not induce excessive corrosion of any vulnerable alloys in the boiler feedwater circuit, including the pumps, piping, and any feedwater heaters or economizers.

The compatibility of BTP was compared to the benchmark previously referenced, and to a common polyacrylate. The data are summarized in Figure 10. Coupon corrosion rates were measured under simulated boiler feedwater/condensate conditions – pH 9.0 adjusted with neutralizing amine; 212°F; and 10 ppb dissolved oxygen. As shown, the corrosion rates measured with Solus AP were on par with the benchmark and lower than the polyacrylate polymer.

