POLYMERIC DISPERSANTS FOR CONTROL OF STEAM GENERATOR FOULING

P.V. Balakrishnan[1], S.J. Klimas[1] , L. Lépine[2] and C.W. Turner[1]

ABSTRACT

Fouling of steam generators by corrosion products from the feedtrain leads to loss of heat-transfer efficiency, disturbances in thermalhydraulics, and potential corrosion problems owing to the development of sites for localized accumulation of aggressive chemicals. This paper summarizes studies of the use of polymeric dispersants for the control of fouling, which were conducted at the Chalk River Laboratories. High-temperature settling studies on magnetite suspensions were performed to screen available generic dispersants, and the dispersants were ranked in terms of their dispersion efficiency; polyacrylic acid (PAA) and the phosphonate - HEDP - were ranked as the most efficient. Polyacrylic acid was considered more suitable than HEDP for nuclear steam generators and more emphasis was given to the former in these studies. The dispersants had no effect on the particle deposition rates under single-phase forced-convective flow, but did reduce the deposition rates under flow-boiling conditions. The extent to which the deposition rates were reduced increased in proportion to the dispersant concentration. Preliminary corrosion tests indicated negligible pitting or general corrosion of steam generator tube materials in the presence of PAA. Corrosion of carbon steel, although higher in a magnetite-packed crevice under heat flux than in bulk water, was lower in the presence of PAA than in its absence. Some impurities (e.g., sulphate, sodium) were observed in commercially available PAA products at small, though significant concentrations, making them unacceptable for use in nuclear plants. However, the PAA could be purified by ion exchange. Preliminary experiments, to assess the thermal stability of PAA at steam generator operating temperature, showed the polymer to break down in deaerated solutions and under argon cover to give hydrogen and carbon dioxide as the 2 major products in the gas phase and variable concentrations of acetate and formate in the aqueous phase. These results suggest that the predominant breakdown mechanism is decarboxylation, rather than depolymerization. More detailed studies on thermal degradation of PAA are in progress. The implications of the results obtained so far with respect to a field trial of dispersant at a nuclear power plant are discussed.

[1]AECl, Chalk River Laboratories
Chalk River, Ontario
Canada K0J 1J0

[2]Institut de recherche d'Hydro-Québec
1800 Boul. Lionel-Boulet, Varennes, Québec
Canada J3X 1S1

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INTRODUCTION

During operation, steam generators become fouled by corrosion products. Deposits form on the tubes, thereby decreasing the efficiency of heat removal from the primary coolant. The flow holes in the steam generator tube-support structures may become plugged, resulting in disturbances in thermalhydraulic behaviour. A sludge pile may collect on the tubesheet, which, along with all other areas with corrosion product deposits, provides sites for solute hideout leading to corrosion problems. The use of dispersants was seen as a possible way of controlling the fouling. A review of the use of dispersants for fouling prevention and control identified a number of potential candidates for such application [1]. From among the potential candidates a few were selected for laboratory evaluation. Because fouling of steam generators can be expected to be minimized by the effective removal of foulants by blowdown, the ability of the candidate dispersants to stabilize a magnetite colloidal suspension was considered a measure of the dispersant's efficiency for fouling control. Screening tests, based on measuring the settling rate of magnetite suspensions, were performed to rank the candidate reagents first at room temperature and then at 250°C [2]. A polyacrylic acid (PAA) and a phosphonate (hydroxyethyl diphosphonic acid - HEDP) were ranked the most efficient. Because phosphate is considered undesirable in steam generators because of possible corrosion concerns, the primary focus was placed on PAA reagents. This study describes further high-temperature dispersion studies, preliminary studies on corrosion of steam generator materials, studies on iron oxide deposition on heat-transfer surfaces and an examination of the hydrothermal stability and breakdown products.

DISPERSION STUDIES

The dispersion efficiency was determined using the settling test procedure [2]. A colloidal suspension of the corrosion product oxide (magnetite in this study), containing the dispersant under test at the desired concentration (usually about 10 mg/kg) and morpholine to give the desired $pH_{25°C}$, was heated in a 2-L Hastelloy-C autoclave to the test temperature (253°C) and was stirred to avoid settling of the oxide during the heatup period. Once steady conditions were attained, the stirring was stopped and liquid phase samples were drawn from the autoclave through a cooler at intervals. The samples were dissolved in hydrochloric acid and the dissolved metallic species (iron) were analyzed using a colorimetric (spectrophotometric) method employing o-phenanthroline. The length of time for which the samples contained a high concentration of iron was taken as a measure of the effectiveness of the reagent.

Several polymers of different composition and molecular weight, obtained from different manufacturers, were tested. For example, PAA-A is a polyacrylic acid of molecular weight 27000 and PAA-B of molecular weight about 3500. In initial tests, all the dispersants tested in the presence of morpholine did not perform as well as they did in the tests reported earlier in the presence of ammonia [2]. Repeat tests, performed in the presence of ammonia, were very similar to those obtained in the presence of morpholine. This behaviour is attributed to the nature of the magnetite used. This is seen in the scatter in the results in the several tests done on the PAA-B (Figure 1), which was found in earlier tests to have the best dispersion efficiency. From Figure 1 it can be seen that PAA-B stabilized the magnetite suspension at about 40-60% of the original concentration (i.e., 10 mg/kg) for up to about 8 h. In the earlier tests, PAA stabilized magnetite suspensions at about 9 mg/kg (90% of the original concentration) for up to 24 h. The dispersion efficiency at $pH_{25°C}$ 9 in presence of morpholine for the reagents tested was found to be in the order:

Polymer-A < Polymer-B < PAA-A (MW 27000)
< Polymer-C < HEDP ≈ PAA-B (MW 3500)

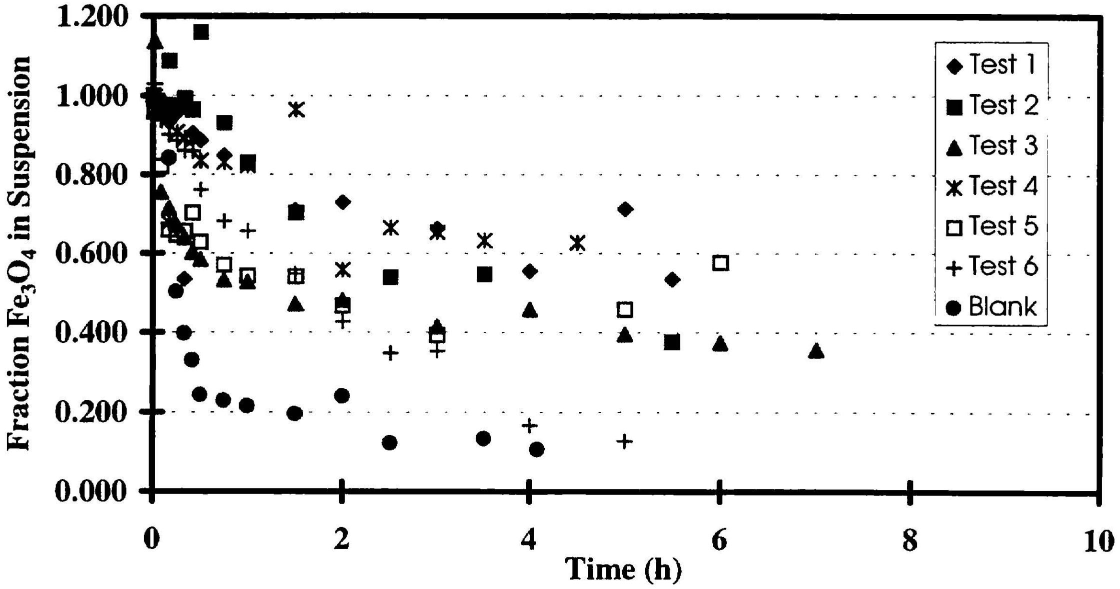

Figure 1: Dispersion of Magnetite at 250°C - 10 mg PAA-B/kg, $pH_{25°C}$ 9 (Morpholine).

DEPOSITION STUDIES

The two top-ranked dispersants from the settling tests were chosen for further tests to determine their effect on particle deposition rates under single-phase forced-convective flow and flow-boiling, representing thermalhydraulic conditions in the feedtrain and the SG, respectively. The experimental procedures used to measure the particle deposition rates have been described elsewhere [3,4]. The loop used for the deposition tests is shown in Figure 1 in Reference 4. Morpholine was used to adjust the pH, and the dissolved oxygen concentration was kept at a negligible level (<5 μg/kg) by maintaining approximately 50 μg/kg hydrazine in the loop. Since the loop was run in the once-through mode, loss of hydrazine by thermal decomposition was not significant and very little difference in the hydrazine concentration between the feed and the effluent was observed. Table 1 lists the conditions under which the loop tests were conducted.

Table 1: Nominal conditions for the particle deposition tests under flow-boiling and single-phase forced convection.

	Flow-Boiling	Forced-Convection
pH_{25} - loop	9.2 - 10.1	9.5 - 10.3
Loop Pressure (MPa)	3.9 - 4.1	5.6 - 5.8
Bulk Water Temperature (°C)	249 - 252	190 - 230
Heat Flux (kW m^{-2})	98 - 134	86 - 111
Mass Flux (kg m^{-2} s^{-1})	135 - 222	263 - 283
Reynold's number at 0 quality	16500 - 21000	18500 - 24500
Exit quality	< 20%	-
Magnetite Concentration (mg kg^{-1})	0.03 - 4.5	0.15 - 1.5

Based on the high-temperature settling tests, PAA and HEDP were selected for loop tests to determine their effect on particle deposition rates. Separate deposition experiments were performed using PAA with molecular weights of 3500 (PAA-B), 5000 (not included in the settling tests), and 27000 (PAA-A). A suspension of colloidal radioactive magnetite was injected continuously into the loop at a rate sufficient to maintain about 1 mg/kg of magnetite in suspension during each run. For most tests in the series, one half of the dispersant was added to the suspension tank to equilibrate with the active magnetite before injection into the loop, and the other half was added to the loop water before the start of the run. The exceptions were the tests with PAA at concentrations of 10 mg/kg and 20 mg/kg (see Table 2), where all of the dispersant was added to the loop water before the injection of magnetite. Deposition on the heated test section throughout each run was monitored by an on-line high-efficiency γ-ray detector.

The results of the deposition tests are shown in Table 2. For simplicity, the deposition rates have been normalized to the average rate measured in the absence of dispersant. The results under flow-boiling conditions have been separated into 2 categories: saturated nucleate boiling with zero net steam quality, and saturated nucleate boiling, averaged over a range of steam qualities from 0 to 20%.

The presence of either low molecular weight PAA or HEDP did not have a significant effect on the magnetite deposition rate under single-phase forced-convective heat transfer conditions.

Particle deposition under these conditions can be modelled as a 2-step process: transport from the bulk to the vicinity of the wall, followed by attachment to the wall. The rate of attachment to the wall is strongly dependent on the relative surface charges of the particle and the wall material. Under conditions where the surface charges are the same sign, there will be a repulsive force acting between the particle and the wall. Thus particles must first acquire sufficient kinetic energy from the fluid to overcome the force of repulsion before they can become attached to the wall. It has been shown experimentally that surface repulsion can lower the particle deposition rate by up to an order of magnitude [5,6].

Table 2: Effect of PAA and HEDP on the particle deposition rate of colloidal magnetite under single-phase forced-convection and flow-boiling heat-transfer conditions.

Concentration (mg/kg)	Normalized Deposition Rate		
	Single-Phase Forced Convection	Flow Boiling	
		$X = 0$	$0 < X < 20$
PAA-B Low molecular weight (MW ≈ 3500 - 5000)			
0.2	0.9	0.71	-
0.6	6.0	0.82	-
6.0	1.5	0.40	-
10	-	0.30	0.35
20	-	0.17	0.20
PAA-A Medium molecular weight (MW ≈ 27000)			
0.6	-	0.45	0.30
6	-	2.4	0.92
HEDP			
0.6	1.06	0.32	0.28
6	1.9	0.18	0.065

X = steam quality (%)

In the tests performed under single-phase forced-convection, one might have expected PAA and HEDP to have reduced the rate of particle deposition by adsorbing onto the surface of the particles. However, previous work has shown that, even without dispersants, the deposition rate of magnetite particles in high-temperature alkaline water is significantly reduced by the force of surface repulsion [3]. In addition, it was inferred from this earlier work that the surfaces of both magnetite and Inconel 600 are negatively charged in alkaline water. Although PAA and HEDP are both weak acids, they are appreciably dissociated under basic conditions, to produce anionic species. Thus the evidence suggests that not only is there already a strong repulsive force acting between magnetite and the surface of Inconel 600 in high-temperature alkaline water that limits the particle deposition rate even in the absence of dispersant, the negative charge on these surfaces will impede the adsorption of the anionic forms of PAA and HEDP and diminish any further effect they might have had on the particle deposition rate. However, there is clearly enough adsorption of the dispersants on magnetite to have a positive effect on dispersion, as seen from the settling tests. This apparent discrepancy between the results of deposition tests and settling tests is yet to be resolved.

Both HEDP and PAA had a significant effect on the particle deposition rate under flow-boiling conditions. Although the reduction in deposition rate was marginal for the low molecular weight PAA at concentrations <1 mg/kg, substantial reductions in deposition rate were achieved for polymer concentrations ≥6 mg/kg. The effectiveness of the low molecular weight polymer was essentially constant over the range of steam qualities examined. The medium molecular weight polymer (MW = 27,000) was relatively effective at reducing the particle deposition rate when used at a concentration of 0.6 mg/kg, but it appeared to be less effective at 6 mg/kg. The results in the latter case, however, are dominated by the high deposition rates measured near zero steam quality, and more tests need to be done to better assess the effectiveness of this polymer as a deposit control reagent. HEDP was more effective on a weight basis than PAA at reducing the particle deposition rate under flow-boiling conditions, and appears to increase in effectiveness as the steam quality increases.

The mechanism by which the dispersants reduce the deposition rate under flow-boiling conditions, but not under single-phase forced-convection, is unclear at this time. Perhaps boiling at the heat-transfer surface concentrates the dispersant so that it adsorbs onto the magnetite particles sufficiently to affect the deposition rate. Alternatively, the dispersant may affect the surface tension of the steam-water interface and, thereby, affect the bubble nucleation and growth process in such a way that the particle deposition rate is altered. In this context, it is perhaps significant that the wall superheats for bubble nucleation were generally lower by 1°C in the runs with dispersant.

CORROSION STUDIES

Preliminary tests were done to assess the corrosivity of PAA and its hydrothermal decomposition products towards CANDU steam generator materials. For these tests, Alloy 600, Alloy 800 and carbon steel A508 Class 2 were chosen. Coupons of these materials (1.5 cm x 1 cm x 0.1 - 0.15 cm) were exposed for periods up to 5 weeks to solutions at 250°C containing PAA-B (MW 3500) (10 mg/kg) and morpholine ($pH_{25^\circ C} = 9.0$) in an autoclave set up as shown in Figure 2. Some of the coupons were placed in magnetite in the cup located on the thermowell carrying the cartridge heater.

The extent of corrosion was determined from the weight change of the coupons and from visual examination. The observed weight change was used to calculate the corrosion rate of the materials. The results so obtained are given in Table 3. A slight increase in corrosion of the Alloy 600 and Alloy 800 coupons was apparent, both in the bulk water and in the heated crevice. The negative corrosion rate values in Table 3 for some samples of these alloys are probably results of small amounts of foreign matter (e.g., magnetite) adhereing to the coupons giving apparent weight gains. Examination in an optical microscope at a magnification of 40X revealed no noticeable signs of localized corrosion. However, susceptibility of these materials to intergranular attack and stress-corrosion cracking is yet to be examined. Carbon steel corrosion was significantly increased in the magnetite-packed heated crevice compared to the bulk. Obviously, the oxide in the crevice produced an oxidizing environment for carbon steel. However, corrosion in the tests that used the PAA was lower than in those that did not use the PAA; the dispersant and its thermal degradation products appear to have an inhibitive effect. It should be noted that in these tests the PAA solution was not replenished, so extensive decomposition would have occurred during the course of the tests. The results of the preliminary corrosion tests suggest that no adverse effects are to be expected on steam generator materials that would preclude testing polyacrylate products in the steam generator.

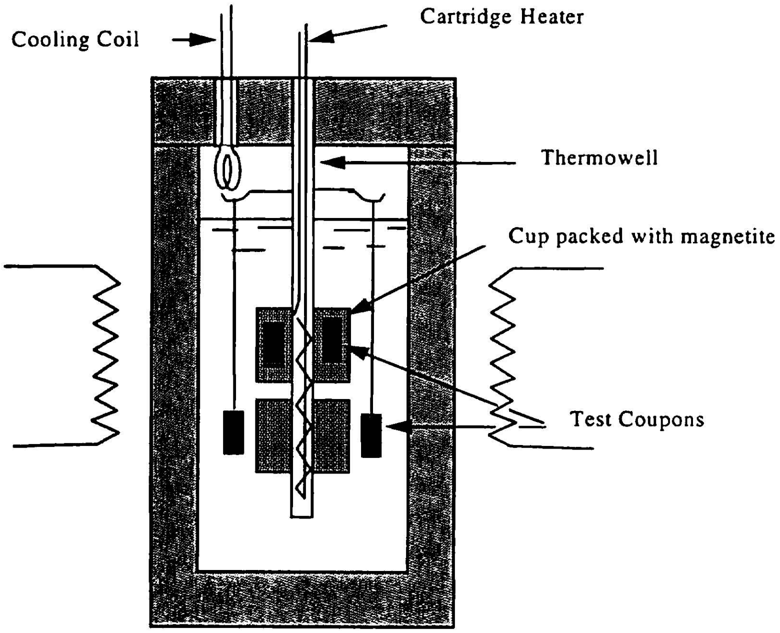

Figure 2: Autoclave setup for corrosion testing.

Table 3: Corrosion rate (mg $dm^{-2}.d$) of steam generator materials in presence of PAA-B at 250°C in crevice and bulk water environments

Material	No Dispersant		10 mg/kg PAA (MW 3500)			
	Crevice	Bulk	Crevice		Bulk	
	330 h	330 h	330 h	718 h	330 h	718 h
Alloy 600	0.0	0.0	0.11	-0.02	-0.04	0.03 ± 0.06
Alloy 800	0.0	-0.13	0.19	0.03	0.09	0.01
CS A508 cl2	25.1	2.9	6.7	11.9	1.1	1.3 ± 0.6

THERMAL DECOMPOSITION STUDIES

The preliminary studies at the Chalk River Laboratories showed the PAA reagents tested to be very unstable in high-temperature (250°C) water in the presence of air [2]. In deaerated solutions, however, the polymers of interest decomposed more slowly with decomposition half-lives that are comparable to the estimated residence time of the polymer in the SG. Gurkaynak et al. studied the decomposition of a 6000 molecular weight PAA in water as a function of pH, ionic strength and temperature [7]. They concluded that the degradation proceeded by a first-order decarboxylation mechanism, which is greatly affected by the pH and to a lesser extent by the ionic strength. The results of preliminary studies at the Hydro-Québec laboratories on decomposition of PAA solutions at high temperatures are described below.

The sodium salt of a PAA standard (average molecular weight 5660) purchased from American Polymer Standards Corporation (Mentor, Ohio) was used. The tests were done in a 2L stainless-steel-316 pressure vessel equipped with a liquid dip (sampling) tube. The PAA solution (50 mg/kg) was placed in the vessel and was degassed by purging with argon for at least 5 min, followed by a succession of argon-purge and vacuum-depressurization cycles. The reactor was then pressurized at 414 kPa with argon and heated at the desired temperature for the required length of time. Samples were drawn during the course of the experiment through the sampling tube into a 40 mL stainless-steel-316 cylinder without cooling down the pressure vessel. The sampling cylinder was previously rinsed with water, then flushed with argon- and vacuum-purged. At the end of the experiment, the pressure vessel was cooled down, and a gas sample was taken through the vent valve and analyzed.

The PAA analysis was performed by size exclusion chromatography (SEC) using differential refractometer and photodiode-array absorbance detectors and a TSK G3000PW column with demineralized water as eluent at a flow rate of 1.0 mL/min. Organic acids were analyzed by ion chromatography using an AS6 anion exclusion column as the analytical column, with heptafluorobutyric acid (0.8 mM) as eluent at 1.0 mL/min and an anion micro membrane suppressor placed after the column with a tetrabutylammonium hydroxide (5 mM) solution circulating at 5 mL/min. The gas phase was analyzed by gas chromatography, at conditions described elsewhere by Jalbert et al. [8]. The gas-phase sample was taken in a 20 mL vial previously flushed with argon and vacuum-purged, after cooling down the pressure vessel to a temperature of ~80°C.

Three tests have been performed so far at 220, 240 and 260°C. The results of the gas-phase analyses at the end of the 3 runs are presented in Table 4. The 2 major products are hydrogen and carbon dioxide, with traces of some light hydrocarbon compounds (ethylene, methane and propane). The presence of carbon dioxide is in agreement with the decarboxylation mechanism proposed by Gurkaynak et al. [7]. In addition, however, we observed the formation of hydrogen, which suggests a free-radical mechanism, such as the one presented in Figure 3, that would produce some unsaturated double bonds on the polymer chain. This mechanism is consistent with the observation, during the SEC analysis, of the increased molar absorptivity in the low UV range for the PAA peak.

The liquid phase was sampled at the beginning and at different intervals during the experiments. As shown in Figure 4, the SEC analyses showed a gradual reduction in the PAA peak (retention time: 5.3 min) and new shoulder and peaks at slightly longer retention time. This means that the degradation products have smaller effective radii in solution than the original PAA does, which would be the case for a decarboxylation mechanism, because it reduces the repulsion between the charges on the polymer and consequently the effective radius in solution.

Table 4: Analysis of the breakdown products from the thermal degradation of PAA (Molecular Weight 5000)

Temperature (°C) →		220	240	260
Duration (h) →		140	143	168
Gas phase:		Concentration (ppm v/v)		
Hydrogen	H_2	2358.9	2547.1	3398.1
Carbon dioxide	CO_2	38.6	333.7	612.5
Ethylene	C_2H_4	2.5	1.8	7.8
Methane	CH_4	2.8	1.8	3.7
Propane	C_3H_8	1.7	1.5	3.6
Liquid phase:		Concentration (μg/kg)		
Acetate as	CH_3COOH	124 - 1406	195 - 638	185 - 2064
Formate as	$HCOOH$	37 - 475	123 - 248	54 - 391
Glycolate as	$HOCH_2COOH$	0 - 135	0 - 65	0 - 169

The ion chromatographic analyses indicated the formation of acetic, formic and glycolic acids; acetic acid being the most abundant. Their concentration levels fluctuated considerably during the course of each of the experiments. Table 4 gives the minimum and maximum values measured at different stages during the experiments, which are only meant to provide a rough estimate of the concentration of these acids that could be formed from PAA degradation.

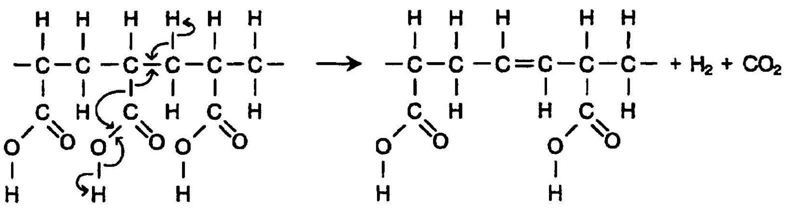

Figure 3: Mechanism for the loss of H_2 and CO_2 during the thermal degradation of PAA

Figure 5 presents the rate of degradation of the PAA (M.W. 5000) standard for the 3 tests at 220, 240 and 260°C, as determined by the height of the PAA peak in the SEC analysis. Only the result at 240°C shows a somewhat linear relation in the logarithmic plot, as expected for a first-order reaction. There is also no logical trend from the lowest to the highest temperature.

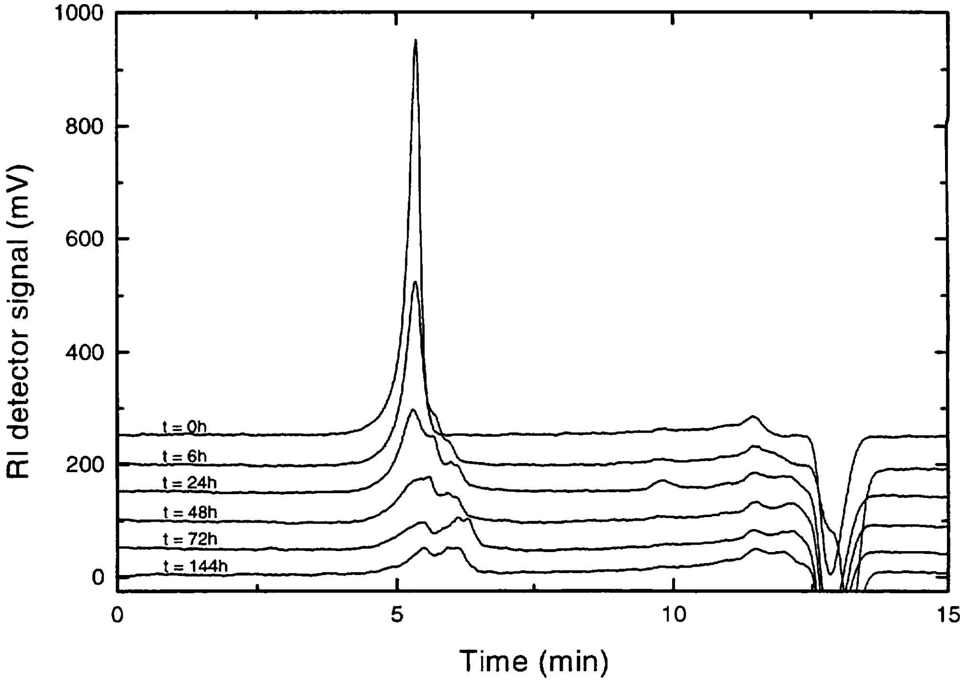

Figure 4: SEC chromatogram of PAA (M.W. 5000) during the thermal degradation at 260°C

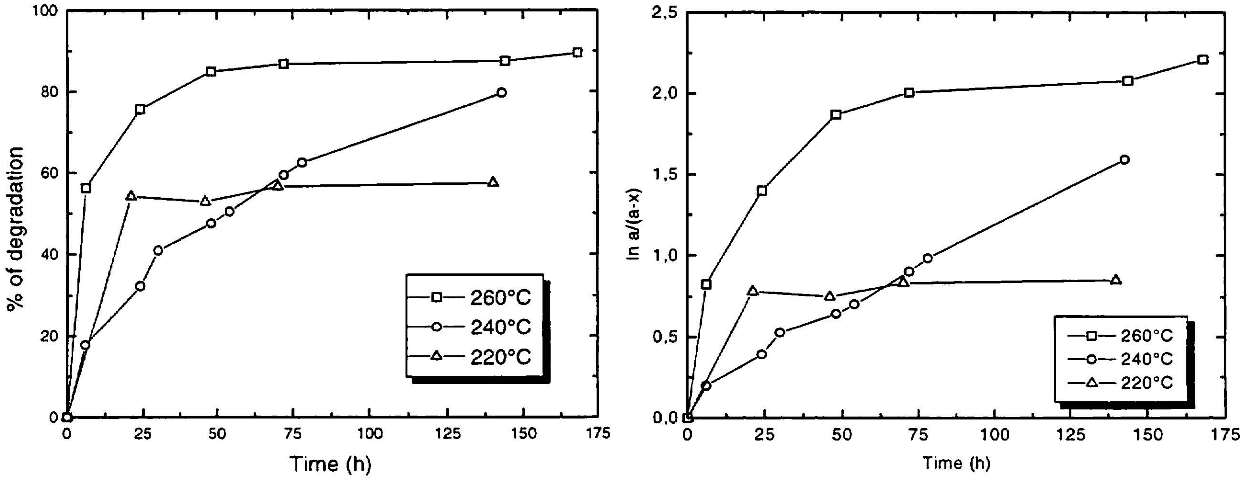

Figure 5: Degradation rate of PAA (M.W. 5000) standard in deaerated water

The degradation tests were run at near neutral pH, under which condition PAA would ionize partially, because PAA is a weak acid. The effect of pH on the decomposition of PAA was not appreciated at that time. Gurkaynak et al. have observed that un-ionized PAA decomposes at a faster rate than the ionized form [7]. The lack of coherent data on the degradation rate and the highly variable amount of organic acids measured during the course of our tests might be explained by the presence of varying amounts of ionized and un-ionized PAA, because the pH of the solution was in a region were small changes in pH would cause large variations in the degradation rate. Further experiments, with the pH adjusted high enough to fully ionize the PAA, will be required to obtain enough coherent data to determine the expected degradation rate under steam generator chemistry conditions.

PURIFICATION OF PAA

Analysis of the commercially available PAA reagents (e.g., PAA-B) by ion chromatography and inductively coupled plasma (ICP) emission spectrosopy showed that they contained significant amounts of impurities, notably sulphur. The sulphur is present mainly as sulphate, since the total sulphur content as obtained from ICP analysis and the sulphate analysis by ion chromatography gave essentially identical results. The presence of sulphate in the PAA is due to the use of persulphates as polymerization initiators during the production. Sodium is present even in the ammonia form of these reagents. Impurities at the levels determined in the reagents would be unacceptable for use in steam generators, since this would cause the concentration of the impurities to exceed the specifications. Obtaining pure PAA either directly from the suppliers or by purifying by suitable means was considered essential, before these products could be considered for use in nuclear steam generators.

Tests were done on ion exchange purification of two PAA products, PAA-B and PAA-C, from different suppliers. The second one, PAA-C, was produced using a sulphur-free polymerization initiator and, hence, is not expected to contain any suphur impurity. Cation exchange resin in the ammonium or hydrogen form was tried for removal of sodium and other metallic cations. Anion exchange resin in the hydroxide form was tried for removal of sulphate and other anionic impurities. The tests were done using solutions which did not usually contain more than 10% PAA. The results for the products in the as-received condition and after the ion exchange purification are given in Table 5 normalized to the neat product (i.e., 100% PAA). Where the results are shown as less than some value, that value was the detection limit for the analysis at the particular concentration of the test solution used. The purification tests were done using different concentrations of the PAA reagents and, consequently, solutions over a range of concentration were analyzed. The detection limit, thus, is reflected at different levels in the results given in the table. The results show that the purification method reduces the impurity concentrations in the PAA products to levels that are sufficient at least for trial tests in nuclear steam generators.

Table 5: Chemical analysis of purified dispersants before and after purification (Concentration of elements in milligrams per kilogram of solution)

Element	PAA-B (Unpurified)	PAA-B (Purified)	PAA-C (unpurified)	PAA-C (Purified)
Al	1.5	<2.5	<20	<0.5
Ba	<0.2	<0.03		<0.6
Cd	<0.3	<0.3		<0.6
Ca	5.2	8.9	<20	<1.2
Cr	4.3	3.4	<20	<1.5
Co	<0.3	<0.25	<20	<1.5
Cu	<0.3	<0.25	<20	<0.5
Fe	18.9	11.5	<1	1.4
Pb	<3	<2		<4
Li	<2.6	<0.6	<20	<1
Mg	<2	<2		<4
Mn	0.45	0.67	<20	<7
Ni	3.6	<1	<20	<2
P	<3	<2.5	<20	<5
K	<10	<10		<10
Na	196	9.0	10,200	<2
Sr	0.035	<0.025	<20	<0.05
U	<5	<10		<20
S	1130	<15	<44	<15

SUMMARY AND CONCLUSIONS

The high-temperature settling studies show that the polymeric dispersants examined have sufficient dispersion ability to make them useful for minimizing fouling in steam generators, especially for minimizing accumulation of sludge piles on the tubesheet. The phosphonate, HEDP, and the polyacrylate, PAA, ranked best in terms of dispersion ability. Because phosphate is not desirable in nuclear steam generators, PAA would be the preferred dispersant for plant use.

Deposition studies using the phosphonate, HEDP, and the polyacrylate, PAA, show that they do not affect the rate of deposition on heat-transfer surfaces significantly, relative to the case without any dispersant, if the heat-transfer mode is forced convection. However, under boiling heat-transfer conditions the deposition rate is decreased by dispersants by 30% to 80% of the rate with no dispersant. The effect increased with increasing dispersant concentration and increasing steam quality. HEDP is more effective than PAA. How the dispersants affect oxide deposition on the heat-transfer surfaces - whether by altering the surface charges or by altering the fluid properties, such as surface tension - is not at present clear.

Preliminary corrosion tests do not show significant effect of PAA and its degradation products on corrosion of steam generator materials. A slight inhibitive effect was seen towards carbon steel corrosion. A very slight increase in the general corrosion rate of steam generator tube materials (Alloy 800 and Alloy 600) was noted, but no localized corrosion is observed. More detailed corrosion studies are planned.

PAA undergoes rapid degradation in high-temperature water in the presence of air. Preliminary studies in deaerated water indicated PAA to be sufficiently stable for plant use. More detailed studies show that PAA degrades in high-temperature water through a decarboxylation mechanism rather than by depolymerization. Hydrogen and carbon dioxide, as well as acetate and formate, are the major degradation products. If dispersant adsorption is important in fouling control, the loss of the carboxyl group in the PAA by thermal decomposition could lead to loss in efficiency of fouling control; the presence of the carboxyl group influences the surface charges. The carbon dioxide and organic acids produced could also be a concern because of possible corrosion in the steam generator and at the early condensation point in the turbines. Because the decomposition kinetics is sensitive to the pH, more rigorous studies under carefully controlled pH conditions are planned to obtain the information necessary to derive the expected usage rate of PAA in steam generators The carbonate/bicarbonate would be determined in these studies in addition to the analyses already performed.

Significant impurities, such as sulphate and sodium, were seen in commercially available PAA reagents. These impurities could be removed using ion-exchange resins, to make the PAA acceptable for plant use, at least for demonstration tests. Source of high-purity PAA products should be identified if this technology is found acceptable for nuclear steam generators.

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