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Bureau of Ships
Washington 25, D.C.

THE REACTION RATE OF SODIUM SULFITE
WITH DISSOLVED OXYGEN

S.J. Rodgers

16 May 1960

MSA Research Corporation

Subsidiary of Mine Safety Appliances Company

Callery, Pennsylvania

Job No. XA-720164
Exp No. 118

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ABSTRACT

The reaction rate of sodium sulfite was studied as a function of oxygen concentration, $\text{Na}_2\text{SO}_3/\text{O}_2$ ratio, temperature, catalyst, pH and surface/volume ratio. The reaction rate of hydrazine with dissolved oxygen was also studied. The reactions were studied in a dynamic stainless steel system. Oxygen concentrations were measured with a modified Bettis dissolved oxygen analyser.

Oxygen removal is incomplete when the sulfite to oxygen ratio is less than the stoichiometric quantity. With the stoichiometric quantities of oxygen and sodium sulfite present, removal is incomplete at 100°F in 1 min, at 200°F , about 95% of the oxygen is removed in 10 sec and at 300°F oxygen removal is essentially complete in 10 sec.

With an excess of sulfite present ($10 \text{ Na}_2\text{SO}_3/1 \text{ O}_2$, molar), 95% of the oxygen is removed at 100°F in 10 sec. At 200 and 300°F , oxygen removal is essentially complete in 10 sec.

The rate of oxygen removal is dependent to some extent on the container material. The sulfite oxygen reaction progresses at a higher rate in boiler water than in feed-water.

The reaction rate of hydrazine with oxygen is low compared with the reaction rate of sulfite and dissolved oxygen. No reduction of oxygen was noted over a one minute period with an excess of hydrazine.

THE REACTION RATE OF SODIUM SULFITE WITH DISSOLVED OXYGEN

S.J. Rodgers

INTRODUCTION

The necessity of maintaining dissolved oxygen at a low level in power plant boilers has long been recognized. The corrosive effects of dissolved oxygen on metallic components has been the subject of many studies in the past and more recently, the contribution of oxygen on chloride stress corrosion of stainless steel boiler components has been investigated. It has been shown that chloride stress corrosion is, for all practical purposes, eliminated when the oxygen level is maintained below 0.05 ppm. It has also been demonstrated that chloride concentrations up to 800 ppm can be tolerated if the oxygen level is limited to less than 0.1 ppm¹.

Two methods are used to remove dissolved oxygen - the mechanical method and the chemical method. Mechanical deaeration, which requires heating, is the method most widely used for the removal of bulk oxygen. The chemical method, which normally entails the use of sodium sulfite or hydrazine, is the most efficient method of removing trace quantities of oxygen.

Both chemicals are compatible with boiler components at the levels necessary to maintain minimum oxygen levels. Sodium sulfite is inexpensive, water soluble and forms a water soluble reaction product with oxygen. The overall reaction of sodium sulfite with oxygen is:

with the stoichiometric weight ratio being 7.88 $\text{Na}_2\text{SO}_3/\text{l O}_2$ and the stoichiometric molar ratio being $2\text{Na}_2\text{SO}_3/\text{l O}_2$. The reaction of hydrazine with oxygen is:

with both the stoichiometric and molar ratios being $1\text{NH}_2\text{NH}_2/\text{l O}_2$. Numbered among the disadvantages of hydrazine are the formation of ammonia with a large excess of hydrazine and the potential explosion and poison hazard of the chemical.

This report describes a systematic study of the reaction rate of sodium sulfite with dissolved oxygen and a less encompassing study of the reaction rate of hydrazine with dissolved oxygen.

EXPERIMENTAL PHILOSOPHY

Study of the reaction rate of oxygen-controlling chemicals with dissolved oxygen must be made under conditions normally encountered in boiler systems. These conditions should be typical of both feed-water and boiler water since oxygen will be controlled in both systems. It is obvious that the conditions under consideration may vary widely from power plant to power plant but some limiting conditions can be set for naval nuclear power plants. An evaluation of the reaction rates within these limits should provide reaction rate data suitable for use by power plant operating personnel.

The effect of temperature is of major consideration in any reaction rate study. The temperatures which will normally be encountered in a Naval plant are in the range of 100-600°F with the 100°F level typical of the feedwater plant and 600°F typical of the boiler. Temperature levels of 100°F, 200°F and 300°F were chosen for this study. The maximum of 300°F was chosen to avoid construction of a high pressure system, with the understanding that if the data warranted, a system would be constructed for evaluation at higher temperature levels.

The oxygen level of air-saturated water at room temperature is of the order of 1-5 ppm. Typical oxygen level of mechanically deaerated water is in the range of 0.01 ppm and trace oxygen levels can be considered to be of the order of 0.005 ppm. Since it is possible that all of these levels may be encountered during normal power plant operation, oxygen concentrations of 0.01, 0.10 and 1.0 were chosen for study.

Specifications for sulfite levels vary from plant to plant and depend upon the oxygen concentration at any given time. Levels of 25, 100 and 300 ppm Na_2SO_3 were originally chosen but results as the test progressed indicated that it was impractical to run extremely low O_2 levels. It was decided that the tests would be run with various $\text{Na}_2\text{SO}_3/\text{O}_2$ molar ratios specifically 0.5 $\text{Na}_2\text{SO}_3/1 \text{ O}_2$, 2 $\text{Na}_2\text{SO}_3/1 \text{ O}_2$ and 10 $\text{Na}_2\text{SO}_3/1 \text{ O}_2$.

The pH level normally maintained is in the range of 7-11. Levels of 7, 8.5 and 11 were chosen for this study.

Although catalysts are not normally employed, it has been reported that cations of heavier metals will catalyze the sulfite-oxygen reaction². The metals include copper, iron, cobalt, nickel and manganese with copper showing the most marked effects. It was also reported that anions and cations of the alkali and alkaline earth metals apparently exert no catalytic effect. Furthermore, substances which form complexes with the ions minimize the catalytic effect. Another reference indicates that cobalt is more effective than copper. An initial O₂ concentration of 8-10 ppm was reduced to 0 ppm in 30 seconds with 0.01 ppm cobalt and to 0 ppm in 4 minutes with 1.0 ppm copper³. Copper was chosen as the catalyst for this investigation and evaluated at the levels of 0, 0.01 and 1.0 ppm. It will be shown later than there apparently is also a surface catalytic effect of the stainless steel container walls which is more predominant than that of the heavy metal ions in solution.

Other factors which, although they do not necessarily vary from boiler to boiler, must be taken into consideration include phosphate level (150 ppm), chlorides (<1 ppm) and solids (800-1000 ppm). These factors were maintained as near to zero as possible for evaluation of reaction rates in feedwater.

EXPERIMENTAL EQUIPMENT AND OPERATION TECHNIQUES

The experimental equipment is shown in Fig 1 and was constructed of Type 304 stainless steel. Two reservoirs each contained 100 gal. of water, one adjusted to the specified oxygen level and the other adjusted to the specified sulfite level. Catalyst, pH and phosphate were adjusted to the desired level in each reservoir prior to each run. Oxygen level was reduced in the oxygen reservoir either by heating the water or adding sufficient sulfite to react with the oxygen present. When necessary, the oxygen level was increased by bubbling air through the water in the reservoir. Sulfite was adjusted by adding a concentrated Na₂SO₃ solution in the appropriate quantity to the sulfite reservoir.

Water was circulated through the test section with a gear pump. Mixing in the reservoir was attained by circulating through the pump and through a by-pass return to the reservoir. Flowrate was measured with flowmeters calibrated for 100% flow equivalent to 0.24 gpm. Initial heating of each of the water supplies was effected in separate tanks with immersion heaters.

Throttling valves provided a means of proportioning the flow from each of the systems, with the total volumetric flowrate through the test sections being 0.24 gpm (1.3 fps). This flowrate resulted in a Reynolds number of 10,000 in the test sections at 100°F assuring turbulent flow. Since the study was on reaction rates and not mixing, that turbulent flow was desirable to minimize anomalies due

Fig. 1 - Flow Diagram - Dissolved Oxygen-Sulfite Reaction Rate Apparatus

to mixing. A mixing chamber was also installed at the junction of the sulfite and oxygen lines and was composed of a 1-1/2 in. length of baffled 1/2 in. pipe. It was felt that the combination of the mixing chamber and turbulent flow would provide sufficient mixing so that the rates which were measured were true reaction rates. As the test progressed a high initial reaction rate was observed. Since residence time (0.2 seconds), surface to volume ratio and mixing was greater in the mixing chamber than in the system proper, it was felt that the measured reaction rates may have been influenced by the mixing chamber. The chamber was replaced with a tee but no difference was noted in measured reaction rates.

Various contact times were attainable with appropriate lengths of 3/8 in. OD tubing. Contact times of 2, 3.5, 5, 10, 30 and 60 seconds were possible with this system. With the exception of the tube corresponding to the 2 second contact time where heat losses were negligible, the test sections were maintained at the desired temperature by an oil bath.

Samples were taken from the reservoirs and analysed for the various additives. Phosphate concentrations were determined colorimetrically using a Taylor Slide Comparator. The range of the method was 10-90 ppm with concentrations above this range analysed after dilution of the sample. Sodium sulfite concentration was determined volumetrically by titrating with iodide-iodate solution. The pH levels were determined with a Beckman pH meter standardized with standard buffer solutions. Chloride concentration was determined colorimetrically using the mercuric thiocyanate method. Solids were measured by evaporating a 100 cc sample of the water and weighing. Copper was determined by the diethyldithiocarbamate method with a lower limit of detection of 1×10^{-4} ppm.

Hydrazine concentration was determined by two methods recommended by Hall Laboratories⁴. The method used for low hydrazine concentrations was the colorimetric method employing p-dimethylamino-benzaldehyde in acid medium. Hydrazine concentrations greater than 1 ppm were analysed by titrating with iodine in a sample buffered with sodium carbonate.

It was recognized that an instantaneous method of analysis for oxygen was necessary to measure the quantity of oxygen present after short contact times considered in this study. The Bettis dissolved oxygen analyser seemed most promising since its operation is based on continuous flow of a sample through the apparatus. Thus, a sample flowing from the 2 second tube into the analyser represents the oxygen remaining after 2 seconds.

A schematic diagram of the analyser is shown. (See Fig 1.) It consists of an upstream ion exchange column, upstream conductivity cell, thallium column, downstream conductivity cell and a downstream ion exchange column if the water is to be returned to the system. Water is passed through the analyser at a flowrate of 150 cc/min and, for this study, a constant temperature of 90°F. Ionic material, but not oxygen, is removed from the water passing through an upstream ion exchange column. Conductivity of the deionized water, which still contains the dissolved oxygen, is measured in the upstream conductivity cell.

Conductivity of the water in the downstream conductivity cell is a function of the quantity of oxygen in the water. Oxygen concentration of the water is calculated using the following equation

$$\text{ppm O}_2 = 3.2 \times 10^4 \left(\frac{K_0}{R_0} - \frac{K_1}{R_0} \right)$$

where K_1 and K_0 are the experimentally determined cell constants for the upstream and downstream cells, respectively. The resistances, R_1 and R_0 , are measured with a conductivity bridge.

Accuracy of the method was determined by comparison with samples analysed by the Winkler Method for high oxygen concentrations and the Indigo Carmine Method for low oxygen concentrations. The results indicated that the oxygen concentration determined with the analyser was representative of the true oxygen concentration.

Some difficulty was experienced when the system was first put into operation. It was observed that after the analyser had run for a period of time, the oxygen concentration apparently dropped. This was found to be caused by reaction of oxygen, which normally would pass through the ion exchange column, with sulfite which had been removed by the column. This difficulty was eliminated by converting the first 25-30% of the resin to the iodate form. Thus, sulfite is converted to sulfate in the column, preventing additional oxygen removal. Reliable results were then attainable until the resin bed became saturated with the normal ionic material found in the water.

DATA AND RESULTS

Introduction

Runs were made by filling the tanks with demineralized water. A sample of water from each tank was passed through the analyser to determine the oxygen concentration and appropriate additions or removal of phosphate, LiOH, sulfite, copper and oxygen were made. Temperature adjustments were made and the run was initiated by

proportioning the flow from the tanks to give the desired $\text{Na}_2\text{SO}_3/\text{O}_2$ ratio. Water was passed through each test section for 10 minutes to assure that the system was flushed. An additional 5 minute flush was passed through the analyzer to assure that the system was equilibrated. The following presentation is, unless otherwise noted, typical of the reaction in boiler water in Type 304 stainless steel.

Reaction Time as a Function of Oxygen Concentration

Oxygen concentrations of 1, 0.1 and 0.01 ppm were considered in this study. These levels were studied with sodium sulfite to oxygen molar ratios of 0.5/1, 2/1 and 10/1 (2/1 molar ratio represents stoichiometric quantities).

Results shown in Fig 2 indicate that the major fraction of oxygen removal occurred during the first 10 seconds. The initial oxygen concentration seemed to have no effect on the characteristic removal during the first 10 seconds. It was noted that at the oxygen levels of 0.1 and 0.01 ppm with a 0.5 $\text{Na}_2\text{SO}_3/1 \text{ O}_2$ ratio the reaction was complete, i.e., 25% of the oxygen was removed within 10 seconds. However, at the 1.0 ppm oxygen level with a 0.5 $\text{Na}_2\text{SO}_3/1 \text{ O}_2$ ratio, greater than 25% of the oxygen was removed (Fig 3). It is believed that this is due to the reaction of oxygen with the tubing walls in addition to the reaction with Na_2SO_3 .

Effect of $\text{Na}_2\text{SO}_3/\text{O}_2$ Ratio

The molar sulfite to oxygen ratios of 0.5/1, 2/1 (stoichiometric ratio) and 10/1 were studied at the oxygen levels of 0.01, 0.1 and 1 ppm. Oxygen concentration versus reaction time is plotted as a function of $\text{Na}_2\text{SO}_3/\text{O}_2$ in Fig 4.

With a 0.5 $\text{Na}_2\text{SO}_3/1 \text{ O}_2$ ratio, removal of oxygen from the system is incomplete. This would be expected since this ratio corresponds to 25% removal of oxygen. An interesting fact which was noted, however, was that as high as 50% of the oxygen was removed using this ratio when the initial oxygen concentration was 1 ppm or higher. As indicated before, this is attributed to reaction of oxygen with the equipment walls.

Straub⁵ has reported that dissolved oxygen will react with both sulfite and steel even in the presence of excess sulfite. He has also reported that sulfite will reduce ferric oxide at temperatures above 450°F. If oxygen is removed by the stainless steel surface, one would expect a ferric oxide to be deposited on the surface which would eventually act as a protective barrier to additional removal by the vessel walls. However, if the ferric oxide is reduced by sulfite a dynamic equilibrium would be produced where in sulfite would be consumed by both the oxygen and ferric oxide and oxygen would be consumed by both the sulfite and steel walls. Results indicate that this is probably true.

Fig. 2 - Oxygen Concentration vs Reaction Time
as a Function of Initial O_2 Concentration

Fig. 3 - Oxygen Concentration vs Reaction Time
as a Function of Initial O_2 Concentration

Fig. 4 - Oxygen Removal as a Function of Na₂SO₃/O₂ Ratio

With a $2\text{Na}_2\text{SO}_3/1 \text{O}_2$ ratio, oxygen removal is incomplete in 60 seconds at 100°F with about 50% removed in 2 seconds, 58% removed in 5 seconds and 60% removed in 10 seconds; little additional removal occurs after 10 seconds. Increasing the temperature to 200 results in oxygen removal of 90% in 2 seconds, 97% in 5 seconds and 98% in 10 seconds; after 60 seconds 99% of the oxygen has been removed.

With a $10 \text{Na}_2\text{SO}_3/1 \text{O}_2$ ratio (5 times stoichiometric ratio), 90% is removed in 2 seconds, 94% is removed in 5 seconds and 95% is removed in 10 seconds at 100°F . At 200, 97% of the O_2 is removed in 2 seconds. At 300°F , 98% of the oxygen is removed in the first 2 seconds; at 10 seconds 99% of the oxygen is removed.

Effect of Temperature

Temperature levels of 100°F , 200°F and 300°F were studied for the three $\text{Na}_2\text{SO}_3/\text{O}_2$ ratios. Temperature levels of 65°F and 150°F were also studied for the $2\text{Na}_2\text{SO}_3/1 \text{O}_2$ ratio. It was found that the effect of temperature was quite pronounced, particularly up to 200°F . Plots of oxygen concentration versus reaction time for the various temperatures at 2/1 and 10/1 $\text{Na}_2\text{SO}_3/\text{O}_2$ ratios are shown in Figs 5 and 6.

Effect of Catalyst

The effect of a catalyst was studied at copper concentrations of 0, 0.01 and 1 ppm with copper added as CuSO_4 . It was surprising to find in light of other work that the addition of catalyst produced no noticeable effect on the reaction rate. Since earlier work (Hitchens) had been performed in glass, it was decided that the reaction time would be studied in a non-metallic system.

The stainless steel system was modified by incorporating a glass system, a Tygon system and later a copper system through which a sample was passed for a 1 minute residence time. Results are listed in Table 1 and plotted in Fig 7. It can be seen that copper does catalyze the reaction, doubling the oxygen removal rate when added at a concentration of 1 ppm. No change is noted when copper is added to a stainless steel system, indicating that inherent catalytic effects of the steel system overshadows any catalytic effect of copper. Reaction rate in copper tubing is much higher than in a non-metallic system but less than in stainless steel.

Effect of pH

The pH levels which were studied were 7, 8.5 and 11. No difference was detected when the reaction rate was studied in stainless steel but the reaction proceeded a little more rapidly in glass at a pH of 8.5 than at either 7 or 11.

Fig. 5 - Oxygen Concentration as a Function of Temperature with Na₂SO₃/O₂ = 2/1

Fig. 6 - Oxygen Concentration as a Function of Temperature with Na₂SO₃/O₂ = 10/1

Fig. 7 - Reaction Time at 65° F as a Function of Container Material

Table 1 - Oxygen Concentration as a Function of Structural Material

Container Material	Copper Concentration (ppm)	Oxygen Removed in 1 minute (%)
Tygon	0	2.5
Tygon	1	4.5
glass	0	5.0
glass	1	10.0
copper	-	38.0
stainless steel	0	50.0
stainless steel	1	50.0

temperature = 65°F, $\text{Na}_2\text{SO}_3/\text{O}_2 = 2/1$, pH = 7.1

Effect of Surface to Volume Ratio

The test sections in which the reaction rates studies were performed had a surface to volume ratio of 10 in^{-1} . The tubing was replaced with a vessel which had a surface to volume ratio of 2 in^{-1} . Little difference was noted in the overall removal of oxygen in 1 minute, but the rate of removal during the first 10 seconds was less pronounced. Typical values shown in Table 2 for a $2\text{Na}_2\text{SO}_3/1 \text{ O}_2$ ratio at 65°F show the effect of surface to volume ratios on oxygen removal rates.

If a surface catalytic effect does exist, the degree of mixing is probably as important as surface to volume ratios. In both cases, good mixing occurred but the mixing rate was higher in the tubing than in the tank type vessel. The difference in mixing rates could account for the difference in the initial reaction rate.

Effect of Simulated Feed Water

The results described thus far were in simulated boiler water which contained 125-150 ppm phosphate, 800-1000 ppm solids and was adjusted to the desired pH with LiOH. For the simulated feedwater study, the only adjustments made were initial oxygen concentration and $\text{Na}_2\text{SO}_3/\text{O}_2$ ratio. Reduction of oxygen in 1 minute was less in feedwater than in boiler water and the degree of removal during the first 10 seconds is less pronounced. Comparison of reaction rate in feedwater and boiler water is shown in Fig 8.

Fig. 8 - Reaction Times in Simulated Boiler Water and Simulated Feedwater

Table 2 - Effect of Surface to Volume Ratio on Oxygen Removal

Contact Time (sec)	Oxygen Concentration (ppm)	
	Surface/Volume Ratio (10 in ⁻¹)	Surface/Volume Ratio (2 in ⁻¹)
0	1.0	1.0
2	0.60	0.80
5	0.55	0.70
10	0.52	0.60
30	0.51	0.53
60	0.49	0.50

Reaction of Hydrazine with Oxygen

The reaction of hydrazine with dissolved oxygen was studied less extensively than the sulfite-oxygen reaction. The reaction was studied in simulated feedwater in the same system used for the sulfite study under the conditions listed below:

oxygen concentration (ppm) - 0.1 and 1.0
hydrazine/oxygen ratio - 1/1 and 5/1
copper concentration (ppm) - 0 and 1
temperature (°F) - 100 and 300

No reaction was observed over a 1 minute period under conditions most conducive to reaction, i.e., 1 ppm O₂, 5NH₂NH₂/1 O₂, 1 ppm copper and 300°F. Data in the literature indicates that the reaction is very slow, with some sources reporting reaction times in hours for those conditions (Straub).

DISCUSSION

This study was undertaken to provide information on the reaction of sodium sulfite with oxygen under simulated power plant systems. It is believed that this study has provided practical data from an operational standpoint. The removal of oxygen from a boiler system can now be evaluated in terms of oxygen concentration, sulfite concentration and contact time.

One of the surprising features brought out by this study was that nearly all of the reaction occurs during the first 10 seconds. The work in reference 5 also indicated a high initial reaction rate. It was felt that this may be a function of system design particularly with respect to the mixing chamber, rather than a characteristic of the $\text{Na}_2\text{SO}_3/\text{O}_2$ reaction. This was checked by removing the mixing chamber and replacing it with a tee. Oxygen removal was checked at 65, 150 and 200°F in simulated boiler water at 2, 5, 10, 30 and 60 seconds. Results show the reaction rate was the same with both the mixing chamber and the tee. Some mixing obviously occurs in the tee and the flowrate was high enough to assure turbulent flow so the overall mixing efficiency in the two methods may not have been particularly different. The surface/volume study may have indicated an effect of mixing in addition to an effect of surface to volume.

The initial oxygen concentration had little effect on the reaction rate when the sulfite to oxygen ratio was held constant. At the highest oxygen concentration (1 ppm), however, there was apparently a reaction of oxygen with the metal walls. Straub reports similar observations in his studies on sodium sulfite and hydrazine. He reported that oxygen reacts with both sulfite and steel even in the presence of excess sulfite. He also reported that above 450°F sulfite will reduce ferric oxide.

It was found that at 100°F a large excess of sulfite does not assure complete removal of oxygen. At 200 and 300°F, better than 95% of the oxygen is removed in 10 seconds with a $2\text{Na}_2\text{SO}_3/1 \text{O}_2$ ratio. With a $10 \text{Na}_2\text{SO}_3/1 \text{O}_2$ ratio at 200 and 300°F, 99 to 100% of the oxygen is removed in 10 seconds. These statements are true for reactions in a stainless steel system and may represent reaction of oxygen with the metal walls and quite likely a catalytic effect of the metal walls.

The effect of pH is practically non-existent in a metal system. Other investigators, who have observed significant changes in reaction rates with changes in pH level, attribute the effect to a complexing or precipitation effect on the catalysts in solution. In a metal system, the catalytic effect seems to be a result of surface effects rather than of ions in solution. Thus, pH level would not be expected to change the catalyst concentration and therefore have no effect on reaction rates.

The preliminary study of the reaction rate of hydrazine with oxygen indicated that sulfite is far superior to hydrazine. Complete removal of oxygen can be attained with an excess of sulfite within 1 minute at 300°F while excess hydrazine results in little, if any, reduction in oxygen in 1 minute.

A practical presentation of the data from an operational standpoint is shown in Fig 9 where the quantity of oxygen remaining after 2 seconds, 5 seconds and 10 seconds is plotted for the three sulfite-oxygen ratios as a function of temperature. The plot shows that with $\text{Na}_2\text{SO}_3/\text{O}_2$ ratios equivalent to or greater than the stoichiometric ratio better than 95% of the oxygen is removed in 10 seconds at 200°F and at 300°F essentially 100% removal is attained in 10 seconds.

CONCLUSIONS

The following conclusions have been drawn from the data generated during this study:

1. With less than the stoichiometric quantity of Na_2SO_3 present, ($0.5 \text{ Na}_2\text{SO}_3/1 \text{ O}_2$, molar), removal of oxygen is incomplete. However, the oxygen may be reduced to a level less than that predicted on the basis of the sulfite available by reaction with the system walls.
2. With the stoichiometric quantity of Na_2SO_3 available ($2\text{Na}_2\text{SO}_3/1 \text{ O}_2$, molar), complete removal of oxygen is not attained at lower temperatures. At 200°F, better than 95% of the oxygen can be removed in 10 seconds and at 300°F oxygen removal is essentially complete in 10 seconds.
3. With an excess of sulfite present ($10 \text{ Na}_2\text{SO}_3/1 \text{ O}_2$, molar), a 10 second contact time results in removal of 95% of the oxygen at 100°F, 99% of the oxygen at 200°F and 100% at 300°F.
4. The sulfite-oxygen reaction progresses at a slightly slower rate in feedwater as compared to boiler water.
5. The reduction of oxygen level with hydrazine over a 1 minute period is so small that the change could not be detected.

Fig. 9 - Per Cent Oxygen Remaining vs Temperature

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