Durability Test Results of Construction and Process Materials Exposed to Liquid and Gas Phase Ozone

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Abstract

The Metropolitan Water District of Southern California performed a study to evaluate materials of construction for use in ozone contactor construction. The concept reactor is a baffled box conduit constructed of concrete with metallic valves, slide gates, etc. for flow control and metallic piping for ozone gas distribution and off-gas collection. The study concluded that ozone by itself has no impact on standard type 2/type 5 concrete and that pozzalonic admixtures could enhance the structural design. Metals exposed to ozone should be constrained to the austenitic grades of stainless steel. Plastics should be limited in their application, elastomers should be limited to Viton-A and EPDM, and none of the elastomers, protective coatings, structural adhesives or joint sealants tested show promise in long term performance.

Keywords

Ozone; Construction Materials; Durability; Ozone Resistance; Concrete; Plastics; Elastomers; Joint Sealants; Coatings; Metals; Adhesives;

Introduction

In advance of the Metropolitan Water District of Southern California's (MWD) ozone retrofit, industry professionals were consulted for materials performance data with little success. As a result, a white paper study was performed to identify materials and methods for ozone contactor construction and materials for use in support equipment and appurtenances. The limited information was summarized to provide preliminary design criteria for materials selection (Rice, Hall and Bellamy) (refer to Table 1). The apparent lack of information on materials performance and the unique requirements to treat MWD's source waters prompted a study to further investigate construction materials for use in the project.

Materials were selected on the basis of their intended application. The concept reactor vessel (ozone contactor) is a reinforced concrete box conduit with concrete baffles, inlet and outlet conduits with isolation valve structures, and wall penetrations for gas piping and instrumentation.

Various concrete admixtures and cementacious grouts were considered for the vessel construction and metal alloys were looked at for use in support equipment such as slide gates, valves, etc. and for gas piping. Plastics and elastomers were investigated for potential use as gasketing materials while joint sealants were considered for use in concrete expansion joints. Structural adhesives were considered to repair cracks and protective coatings were investigated for potential application.

The initial study looked at materials performance in blended Colorado River and Sacramento-San Joaquin Delta, California State Project, source waters subjected to ozone. This paper will discuss the results of the study and the implications to ozone contactor design.

Methods

The study was accomplished through the use of an 86,000 gpd pilot plant constructed in LaVerne California. The pilot plant consisted of a blend tank, an ozone contactor, a packaged conventional treatment plant and a clearwell (refer to Figure 1). Ozone gas was generated from oxygen using two plate type Griffin GTC 2A ozone generators. Test venues were incorporated in the ozone contactor, the ozonated water stream, the off-gas stream, and in the finished water stream. The pilot plant was operated to induce a 0.4 mg/L ozone residual in test venues 3 and 4 referred to here as the "side stream". Test specimens were subjected to an estimated ozone in water concentration of greater than 4 mg/L in the ozone contactor (test venues 1 and 2), and greater then 1 weight percent in the off-gas stream (test venues 7 and 8).

TABLE 1
OZONE DISINFECTION SYSTEMS CONSTRUCTION MATERIALS COMPATIBILITY CHART
BASED ON LITERATURE SURVEYS & SERVICE EXPERIENCE

Service Area or Area of Application	Service Condition or Environment	Function or Component	Material Type and Designation	Comments
Air Preparation Equipment and Components	Ambient air & compressed air.	Piping, fittings, flanges, tanks, pressure vessels, valves, desiccant dryers, compressors, etc.	Carbon steel, cast iron, aluminum	For use up to but not including isolation valves for the ozone generator feed systems; conventional gaskets materials may be employed.
	Warm humid air.		304 & 316 S.S.	
Oxygen Preparation Equipment and Components	Treated as wet oxygen-rich gas.	Piping	304 & 316 S.S.	Where no welding is required.
		Piping	304L & 316L S.S.	Where welding is required. The TIG welding process should be employed using compatible electrode materials.
		Fittings & Flanges		Compatible with piping.
		Gate Valves - Trim - Packing	 Bronze Virgin PTFE	Minimum of 150#, ANSI class flanges.
		Butterfly Valves - Body - Seat - Stem - Bushing	 Cast Iron Bronze, 304 S.S. & 316 S.S.; Buna-N 304 & 316 S.S. Bronze	Wafer type; minimum of 125#, ANSI class flanges.
	Dry Oxygen Gas	Piping	Carbon Steel	Polished welds; used in Europe, max velocity for Oxygen 8 m/s (26 ft./s)
Ozone Generating Equipment and Components	Dry Ozonized Gas	Ozone Generator	316 & 321 S.S.	Non-welded applications.
			316L & 321 S.S.	Welding process - TIG and approved electrode materials; also applies to cooling water jacket.
		Piping	304 & 316 S.S.	Non-welded applications.
			304L & 316L S.S.	TIG welding with compatible electrode materials.
		Valves - Gasket - Body - Shaft - Disc - Seat - Seal	 PTFE filled Viton-A lined cast iron or 316 S.S. 316 S.S. 316 S.S. Viton-A Viton-A	
Contactor and Destruct System (including recycle streams)	Wet Ozonized Oxygen rich gas	Piping, Fittings, Flanges, Valving, Demisters, Destruct Cabinets, etc.	316 & 316L S.S.	Not directly associated with ozone contactor construction, but applies to all other appurtenances.
		Head Space Seals & Gas Stops	PTFE, 316 S.S., Hypalon	
		Contactor	Type II & V Portland Cement	Use low water to cement mix ratio
		Reinforcing Bar	Galvanized or 10% oversized	Minimum cover, 2 inches of concrete.
		Fittings, Hatch Ways, Vents, Valves, etc.	316L S.S.	Especially concrete penetrations.
Contactor Wetted Parameter	Aqueous Ozone	Water Bearing Structures, Electrical Conduit	Type II & V Portland Cement, PVC and 316 S.S.	Use conventional water stops, water filled in Contractor area.

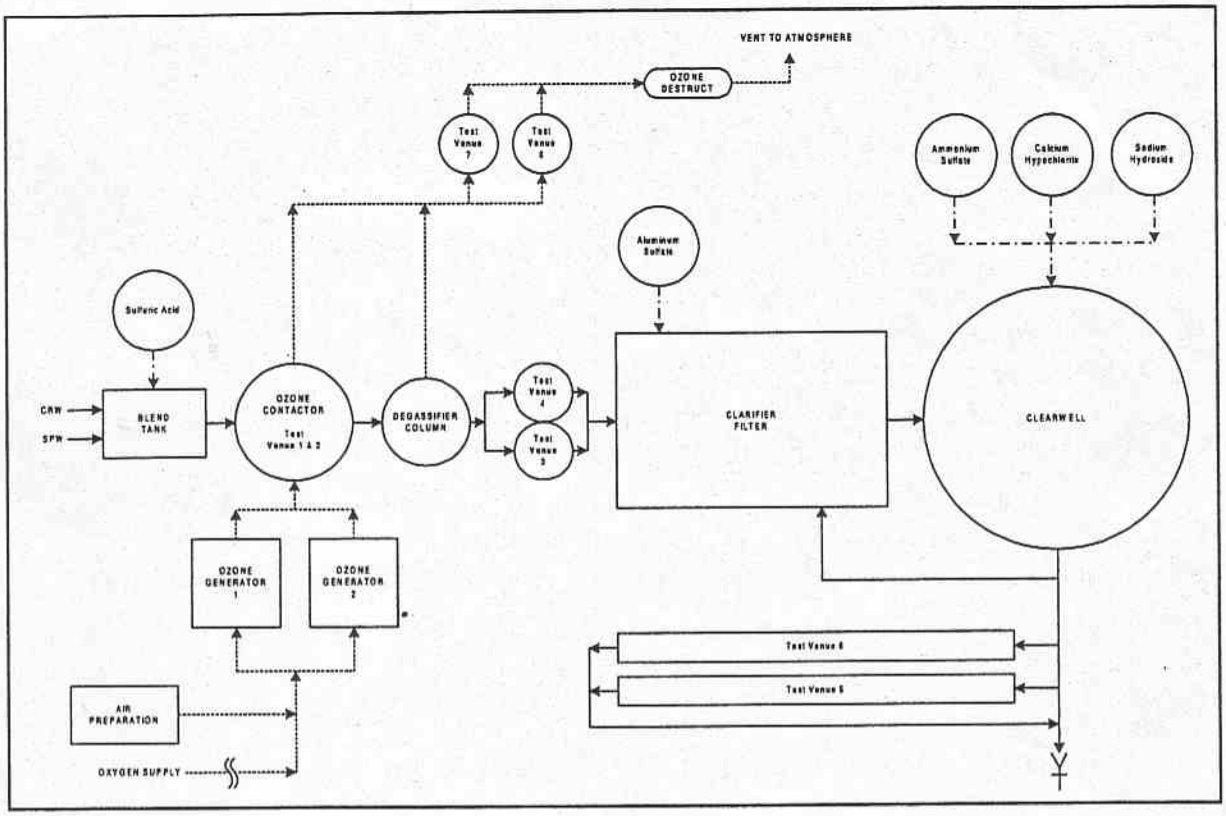

Figure 1. Schematic of Pilot Plant

Specific materials to be tested were selected on the basis of their exceptional durability relative to other materials in the same class. For example, the polyamine epoxies selected for this study have undergone extensive materials testing and evaluations in water immersion and represent the best performing materials of this class. They therefore will be treated as a surrogate for each class of materials. Exposed test specimens were compared against control samples or against test specimens exposed to the finished product water both qualitatively and quantitatively to determine their respective performance and hence give a general indication of their respective durability in each of the environments. The duration of exposure for all test specimens was 180 days under ambient conditions.

Results

Test results are presented in tabular form in the following sections. Each section provides a brief discussion of the class of material and its potential application in an ozone environment, how the test was performed or what methods were utilized, a description of the evaluation process, a description of the test specimen configuration, and a general summary of the findings and or the limitations of the test.

Specific sections included in order are: Concrete and Grout, Metal Alloys, Elastomers, Plastics, Protective Coatings, Structural Adhesives and Joint Sealants.

Concrete and Grout

Concrete and grout testing was accomplished by exposing 2" diameter by 4" tall cylinders to the respective environments. Due to the size of the cylinders, sand was substituted for the aggregate and the sand/cement/water ratio was held to 2.64/1.0/0.57. Test specimens consisted of type 2 and type 5 Portland cement, 18% and 35% fly ash, 5% and 15% silica fume, Speed Crete (TM) and Rapid Set (TM). The fly ash and silica fume replaced a fractional portion of the cement as specified. Grouts were mixed according to the manufacturer's instructions. Five test specimens each were tested and evaluated.

The evaluation consisted of making visual observations for signs of deterioration and compression load testing. Compression test results are reported in Table 2. In general, all test specimens appeared to be in good condition upon removal with the exception of the Rapid Set. The Rapid Set test specimens developed cracks in the wetted environments including the ozone contactor, side stream and the finished water. Two of the test specimens removed from the side stream fell apart while attempting to load them into the universal testing machine used to perform compressions tests. No visual evidence of deterioration appeared on any of the other test specimens.

Metal Alloys

Metal alloys were tested to determine their usefulness in ozone bearing environments. Testing was accomplished using the gravimetric weight loss method. Metal coupons having dimensions 1" wide by 2" long by 1/8" thick with a 3/8" diameter center drilled mounting hole were weighed, mounted on test racks taking care to electrically isolate each individual coupon, and then exposed to the respective environments. Test samples were run in triplicate. Upon removal, the test specimens were cleaned using a soft bristle brush and water. Where a tenacious corrosion layer was present, the metal coupons were cleaned in accordance with ASTM G1, "Recommended Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens." The specimens were again weighed and their respective weight loss or gain was recorded.

The weight change and exposure duration was used to calculate uniform corrosion rates in mils per year. Average corrosion rates for each metal sample is presented in Table 3. Negative values indicate a weight gain representing the development of corrosion products that could not be removed in the cleaning process. The assumption of uniform corrosion implies that the corrosion rate represents the uniform wall penetration rate or rate of loss in wall thickness of metallic vessel or structure.

The test results indicate that the stainless steels are the most resistant to corrosion followed by the copper based alloys, the active metals and finally the carbon steels. The active metals experienced a pitting rather than a uniform type of corrosion and therefore should be used with caution. The tests further indicated that the corrosion experienced by the metal alloys is worse in the liquid phase compared with that of the gas phase ozone.

TABLE 2
COMPRESSION TEST RESULTS OF CEMENT BASED MATERIALS
Compression Load (Lbs)

Location	Type II	Type V	Type V + 18% F.A.	Type V + 35% F.A.	Type V + 5% S.F.	Type V + 15% S.F.	Speed Crete	Rapid Set
Contactor	16730	15510	15050	14920	16360	23560	10020	7007
	17430	16940	15920	16720	16090	25310	10910	11640
	17070	15100	12760	15430	17400	26440	9950	13740
	15680	13190	16030	14740	17320	28060	9700	10150
	16430	12550	14110	13160	15690	24750	10930	11510
Off Gas	15270	19290	18940	16460	16710	23980	13430	11500
	18930	22830	16490	17510	26000	23440	10960	10590
	17850	19980	17840	15620	19800	22310	12890	10510
	19900	19460	17470	12670	16080	26790	9998	13840
	14220	22230	18070	15520	11470	26580	13560	16690
Side Stream	14580	13320	12990	12910	19880	18010	9688	14190
	16450	16320	17260	15760	20460	26810	10510	no value
	18490	16320	13570	15080	14970	21910	8996	no value
	15620	15700	13470	14750	16120	26010	7977	11830
	11340	19220	13400	15920	14970	24890	7530	9326
Finished Water	11770	16360	14370	14060	14020	21900	7119	13680
	10750	14030	15850	12960	13760	29400	11830	10810
	14380	15780	15480	13710	20150	25340	8790	12380
	16570	14640	15790	15250	15930	24400	11010	5746
	13580	15900	14460	13070	15390	18790	10850	10480
Wet Control	17250	14190	11040	13060	12830	25320	8746	8593
	12660	16660	12060	13280	16860	27160	7808	11450
	12580	14400	12720	8649	16650	25630	10600	12290
	11920	13640	12180	12590	15160	25850	8513	15930
	13970	13360	14920	12340	12100	27310	5380	8368
Dry Control	12810	17260	15270	15410	13480	20350	11620	10320
	14840	14960	16650	12360	17060	19660	14060	10610
	14500	14620	16110	13660	20110	17320	7836	6650
	16260	15220	16770	13180	18400	26250	10350	12700
	no value	15070	15330	15120	12360	25870	7440	11200

Elastomers

Elastomers were evaluated for their potential as gasketing materials. Test specimens were obtained from commercially available sheet stock. Four-inch long tensile test specimens with a 1/4" necked down region were prepared in accordance with ASTM D412, "Test Methods for Rubber Properties in Tension." The test specimens were individually labeled and exposed in their respective environments. Upon removal both scleroscope hardness and breaking strength were measured. Test specimens were run in triplicate and the results were averaged. Average tensile test results are shown in Table 4 and average scleroscope hardness values are presented in Table 5. The tensile test results are presented as breaking strength in pounds force for comparison purposes and the hardness is presented as Shore A scale hardness readings.

The test results indicate that both EPDM and Viton-A are resistant to ozone under the conditions of exposure and the duration of testing. All other elastomers have deteriorated to some degree.

TABLE 3
CORROSION RATE OF METAL ALLOYS
(mils per year)

METAL ALLOY	CONTACTOR	OFF GAS	SIDE STREAM	FINISHED WATER
STAINLESS STEELS				
304 S.S.	0.007	0.006	-0.001	-0.007
304 S.S. Welded	0.007	0.008	0.002	-0.002
316 SS	0.002	0.002	0.004	0.004
316 SS Welded	0.006	0.007	0.002	0.002
410 SS	0.034	0.003	0.006	0.000
410 SS Welded	0.020	0.000	0.013	-0.029
430 SS	0.004	0.004	0.000	0.001
CA-6NM SS	-0.002	0.005	0.014	0.012
17-4PH SS	0.001	0.001	-0.006	0.001
Nitronic 60 SS	0.003	0.003	0.001	0.000
COPPER BASED ALLOYS				
CDA-706 (Cu/Ni Alloy)	0.361	0.498	0.184	0.015
CDA-655 (Si Bronze)	0.343	0.017	0.240	0.098
CDA-230 (Red Brass)	0.861	0.048	0.344	0.090
CDA-240 (Low Brass)	1.086	0.040	0.349	0.092
IRON BASED ALLOYS				
ASTM A285 Mild Steel	9.567	0.341	4.348	3.192
ASTM A515 Mild Steel	8.488	0.527	4.522	3.040
1010 Plain Carbon Steel	8.709	0.169	4.420	2.565
4140 HSLA Steel	9.231	0.340	4.495	3.092
4340 HSLA Steel	7.513	0.070	3.304	2.786
Grey Cast Iron	4.296	0.629	4.809	4.226
Hot Dipped Galvanized Steel	4.926	0.007	1.674	1.203
Durachlor-51	0.008	0.000	0.012	-0.962
ACTIVE METALS				
Magnesium	3.056	-0.460	1.993	2.480
Zinc	6.573	-0.019	3.855	1.431
Aluminum 6061	5.369	-0.004	2.319	1.199
Aluminum 5054	4.440	-0.004	1.909	0.758

TABLE 4
BREAKING STRENGTH OF ELASTOMERS
Tensile Load (LBS)

MATERIAL	CONTROL	CONTACTOR	OFF-GAS	SIDE STREAM	FINISHED WATER
Red Silicone Rubber	25	12	10	17	21
Hypalon Rubber	41	25	23	20	18
Viton "A" Rubber	9	10	6	8	10
Ethylene propylene dimonomer (EPDM) Rubber	13	10	11	13	14
Natural Gum Rubber	47	43	Disintegrated	84	69
#2 Natural Gum Rubber		Disintegrated	Disintegrated	23	24
Polychloroprene, Neoprene, Rubber	34	35	Disintegrated	38	34
Buna-N, Nitrile, Rubber	31	20	Disintegrated	25	23

TABLE 5
DUROMETER HARDNESS OF ELASTOMERS
(Shore A)

TEST SAMPLE	CONTROL	CONTACTOR	OFF-GAS	SIDE STREAM	FINISHED WATER
Red Silicone Rubber	59	62	64	58	59
Hypalon Rubber	65	56	62	45	46
Viton "A" Rubber	75	83	80	67	67
Ethylene propylene dimonomer (EPDM) Rubber	74	75	70	70	73
Natural Gum Rubber	44	45	Disintegrated	45	43
#2 Natural Gum Rubber	44	Disintigrated	Disintegrated	42	37
Polychloroprene, Neoprene, Rubber	63	58	Disintegrated	55	56
Buna-N, Nitrile, Rubber	59	59	Disintegrated	57	57

TABLE 6
BREAKING STRENGTH OF PLASTICS
Tensile Load (LBS)

MATERIAL	CONTROL	CONTACTOR	OFF-GAS	SIDE STREAM	FINISHED WATER
Acrylonitrile-butadiene-styrene (ABS) Thermoplastic	136	127	134	139	142
Polyvinylchloride (PVC) Thermoplastic	150	140	151	156	149
Chlorinated Polyvinylchloride (CPVC) Thermoplastic	306	282	292	301	293
Low Density Polyethylene (LDPE) Thermoplastic	47	45	43	50	54
High Density Polyethylene (HDPE) Thermoplastic	180	150	158	163	171
Ultra High Molecular Weight Polyethylene (UHMWPE), Tivar, Thermoplastic	197	183	190	190	203
Polypropylene (PP) Thermoplastic	161	131	161	161	165
Polytetrafluoroethylene (PTFE), Teflon, Thermoplastic	69	64	67	69	79
Durlon 9000	59	57	59	64	64
Clear Vinyl Thermoplastic	83	72	78	75	80

TABLE 7
DUROMETER HARDNESS OF PLASTICS AND ELASTOMERS
(Shore D)

TEST SAMPLE	CONTROL	CONTACTOR	OFF-GAS	SIDE STREAM	FINISHED WATER
Acrylonitrile-butadiene-styrene (ABS) Thermoplastic	69	67	70	70	70
Polyvinylchloride (PVC) Thermoplastic	82	81	80	84	72
Chlorinated Polyvinylchloride (CPVC) Thermoplastic	81	79	83	80	82
Low Density Polyethylene (LDPE) Thermoplastic	50	50	52	52	52
High Density Polyethylene (HDPE) Thermoplastic	75	75	75	76	75
Ultra High Molecular Weight Polyethylene (UHMWPE), Tivar, Thermoplastic	68	68	69	70	64
Polypropylene (PP) Thermoplastic	77	79	77	77	78
Polytetrafluoroethylene (PTFE), Teflon, Thermoplastic	60	58	58	61	61
Durlon 9000	61	58	59	60	64
Clear Vinyl Thermoplastic	95	93	95	95	96

TABLE 8
PROTECTIVE COATINGS FOR STEEL STRUCTURES

COATING (Type & Manufacturer)	CONTACTOR	OFF GAS	SIDE STREAM	FINISHED WATER
3M – Scotchkote 306, High Solids Amine Epoxy (Self Priming, Green)	Heavy fade, material wipes off, moderate rust on edges	Moderate to heavy fading, tiny to small blisters; all samples material is damp and wipes off, very light rust on a couple of spots on the coupons radii.	Moderate fading with heavy chalking.	Slight fading.
Tnemic - Series 20 Pota-pox Polyamide Epoxy over Tnemic Series 66-1211 Polyamide Epoxy Primer (White)	Very heavy chalking, coating wipes off.	Material is deteriorating, damp and wipes off, light rust on coupons radii, very heavy chalking, several tiny blisters.	Very heavy chalking, coating is deteriorating and wipes off.	Good condition.
Pittsburgh Paints - (97-640) Coal Tar Epoxy Paint (Black)	Heavy fading, light to moderate rust on coupon radii.	Heavy fading, rough surface and material wipes off, heavy chalking.	Heavy fading with very light chalking.	Good condition.
3M - Scotchkote 309, 100% Solids Amine Cured Epoxy (No Primer, Lt. Green)	Moderate to heavy fading, moderate chalking.	Material deteriorating, rough surface, material is damp and rubs off, light chalking.	Moderate fading with heavy chalking.	Slight fading.
Devcon - Brushable Ceramic Repair System (Ruddy Brown)	Very heavy fading , very rough surface, mderate to heavy rust on coupon radii.	Heavy fading, material is soft and wipes off, moderate to heavy rust on coupon radii.	Heavy fading with a very rough surface, pinholes over entire surface with moderate to heavy rust tubercles along edges.	Good condition.
Durall Plastics Inc - #47 Aqua Vinyl Ester (No Primer, Aqua Blue)	Slight fading, moderate rust on coupon radii.	Very heavy chalking, slight discoloration on surface.	Moderate fading.	Moderate fading.
Durall Plastics Inc - #47 Polyester (Aqua Blue)	Slight fading.	Very heavy chalking, couple of rust spots on corners of one coupon.	Slight to moderate fading.	Good condition.

TABLE 9
PROTECTIVE COATINGS FOR CONCRETE STRUCTURES

COATING (Type & Manufacturer)	CONTACTOR	OFF GAS	SIDE STREAM	FINISHED WATER
3M - Scotchkote 306, High Solids Amine Epoxy (Self Priming, Green)	Heavy fading, heavy chalking, few pinholes.	Heavy fading, pinholes, material damp and wipes off with heavy chalking.	Heavy fading, light chalking and pinholes.	Slight to moderate white film.
Pittsburgh Paints - (97-640) Coal Tar Epoxy Paint (Black)	Very heavy fading with very light chalking.	Very heavy fading and material wipes off.	Very heavy fading, light chalking and few pinholes.	Very slight fading.
3M - Scotchkote 309, 100% Solids Amine Cured Epoxy (No Primer, Lt. Green)	Heavy fading with heavy chalking and pinholes over most of the surface.	Heavy fading, material deteriorating, pinholes on all test blocks, material wipes off.	Heavy fading, pinholes over most of the sample and light chalking.	Good condition.
Devcon - Brushable Ceramic Repair System (Ruddy Brown)	Very heavy fading, very rough surface (gritty), several pinholes.	Heavy fading, material deteriorating, material wipes off, discoloration and pinholes.	Very heavy fading and very rough surface.	Slight white film.
Durall Plastics Inc - #47 Aqua Vinyl Ester 406.006 (No Primer, Aqua Blue)	Light to moderate fading with pinholes over most of the surface.	Very heavy chalking with several pinholes.	slight to moderate fading.	Slight white film.
Durall Plastics Inc - #47 Polyester (Aqua Blue)	Slight fading.	Heavy chalking.	Slight to moderate fading with a few pinholes.	Good condition.

Plastics

Similar to the elastomers, the plastics were obtained from commercially available sheet stock and test specimens were prepared and tested in the same fashion. Test results are presented in Tables 6 and 7. Test results indicate that all of the plastics that were tested are resistant to ozone under the conditions and duration of exposure.

Protective Coatings

Protective coatings were evaluated for their potential application in an ozone environment. Testing was accomplished by applying the coating system in accordance with the manufacturers written instructions to both steel panels and concrete blocks. The steel panels consisted of a 3" wide by 5" long by 1/4" thick steel plate with a 5/8" diameter hole punched on one end. The hole was used to suspend the test specimens. The concrete blocks consisted of a 2" by 2" by 5" long cast concrete block. Prior to coating application both substrates were abrasive blast cleaned to achieve a 3 to 5 mil surface profile and immediately coated. Stainless steel identification tags were attached to each test specimen. The test specimens were run in triplicate. After exposure, the specimens were removed and visually examined for signs of deterioration. Observations are presented in tables 8 and 9 for the steel panels and concrete blocks respectively.

In general, the test results indicate that no liquid applied coating has adequate resistance to deterioration under the conditions and duration of exposure.

Structural Adhesives

Structural adhesives are generally used for concrete repair. They come in two forms, a paste type and a low viscosity type. The paste type is generally used for surface defects and the low viscosity type is used to inject and repair cracks. These materials were tested to identify potential maintenance repair materials in an ozone contactor. Testing was accomplished through the use of shear blocks and tensile cross blocks.

Shear blocks consisted of cylindrical cement wedges cast with a 30-degree face to the principal axis. Adhesive is applied to the face of two of the wedges and the faces are brought together forming a cylinder with dimensions 5-1/2" tall by 3" diameter. The cylinders are tested in compression after exposure. Each material is tested in triplicate. Test results of compression tests are presented in Table 10.

Tensile cross blocks consisted of two 2" by 2" by 5" long concrete blocks that are bonded with adhesive. Each block is rotated 90 degrees as measured from the long axis thus forming a 2" by 2" adhesive joint centered on the long side of each block. The blocks are tested in tension using the universal testing machine that has been outfitted with a special fixture developed for this test. Test results are presented in Table 11. Ideally, test specimens would fail by overloading the concrete substrate leaving the adhesive in tacked. The shaded regions in the table represent a partial bond failure indicating that the adhesive has been negatively impacted by the environment. Based on these test results it appears that no structural adhesive will guarantee long-term durability at least under the conditions of exposure.

Joint Sealants

Expansion joints in concrete water bearing structures generally consist of a waterstop, joint filler and a joint sealant. This configuration is also used to prevent vacuum or gas leaks in concrete structures such as an ozone contactor. Although the waterstop is the primary membrane, the joint sealant is an integral part of the seal that is in direct contact with the environment. Three common classes of joint sealant materials generally used in this type of construction are polysulfides, room temperature vulcanizing (RTV) silicon and polyurethane.

Test specimens consisting of an 8"x8"xl-1/2" cement block with three 3/4" wide by 3/4" deep parallel grooves running lengthwise and filled with joint sealant were prepared and installed in their respective locations for the duration of the test. Upon removal they were subjectively evaluated for signs of deterioration. The test results are presented in Table 12. The results indicate that all three materials are effected by ozone to some degree. Material degradation was immediately apparent on the polysulfide and polyurethane sealant test specimens upon removal. The silicon appeared to be in good condition, however, the silicon sealant was observed to have disbonded and hardened one month later once it was allowed to air dry under laboratory conditions.

TABLE 10
SHEAR STRENGTH OF STRUCTURAL ADHESIVES
Compressive Load (Lbs)

	Manufacturer & Product		
Test Location	Select Products GP3000	Select Products Select Bond Polyester	Sika Corporation Sikadur 52
Control	19000 17000 17400	33600 26600 26800	31400 24600 21800
Contactor	12800 11400 12400	13200 14600 9200	10000 9600 10000
Off Gas	11600 9000 10200	6600 14600 11200	10200 7800 9200
Side Stream	9400 8800 11600	18200 16800 20600	10400 6800 14000
Finished Water	10400 12000 10200	15600 18000 13200	7800 6800 9000

TABLE 11
BREAKING STRENGTH OF STRUCTURAL ADHESIVES
Tensile Load (Lbs)

	Manufacturer & Product		
Test Location	Select Products GP3000	Select Products Select Bond Polyester	Sika Corporation Sikadur 52
Control	1678 1218 1570	1087 1672 1033	1435 1169 1143
Contactor	1468 1099 1428	1335 1380 1571	1376 1408 1595
Off Gas	1695 1769 1622	620 1335 780	1419 1061 1769
Side Stream	1545 1193 1459	1346 474 1637	1317 1053 1042
Finished Water	1826 1164 1762	691 977 1262	1957 1903 1563

TABLE 12
EXPANSION JOINT SEALANTS

SEALANT (Type & Manufacturer)	CONTACTOR	OFF GAS	SIDE STREAM	FINISHED WATER
Select Products - Select Seal T-227, Two Component Polysulfide Sealant (Pourable Grade, Gray)	Slight to moderate darkening with good adhesion, pinholes on all of each sample.	Sealant deteriorated, crumbles when touched.	Heavy darkening, sealant soft and sticky, rubs off.	Good condition with good adhesion.
Dow Corning - 100% Silicone Bathtub Caulk & Sealant (White)	Good condition with good adhesion. Hardening and disbonding observed one month after removal.	Slight discoloration and good adhesion. Hardening and disbonding observed one month after removal.	Good condition with good adhesion. Hardening and disbonding observed one month after removal.	Good condition with good adhesion.
Select Products - Select Seal U-227 Type II Polyurethane Sealant (Gray)	Heavy white film, good adhesion.	Sealant deteriorated, heavy surface cracking, disintegrates when touched.	Moderate darkening and good adhesion.	Good condition with good adhesion.

Discussion

In order to discuss the implications of the test results we must put it in the context of our concept reactor. The reactor will be constructed largely of concrete with penetrations for gas piping and water passage. The walls, floor and ceiling are the primary membrane for containing the water to be treated and the gas used for disinfection. The results indicate that standard type 2 and type 5 concrete mix designs are sufficient for this type of construction and that pozzalonic admixtures, used for strengthening concrete, can be taken advantage of to reduce section thickness of the load bearing support structures. We are assuming that sound engineering principals are used in the design and that good construction practices including quality control are in affect during construction.

Due to the size of our concept reactor, expansion joints are necessary to accommodate thermal expansion and other types of movement. Expansion joints for this type of structure require the use of a water stop, a filler material and an expansion joint sealant. Considered the first line of defense to prevent water or gas leaks, water stops are generally plastic such as flexible PVC or thermal plastic elastomeric rubber (TPER), or stainless steel. The results indicate that stainless steel would be adequate, however the flexible PVC and TPER were not tested and therefore cannot be commended on. The secondary line of defense is the joint sealants. The results indicate that all three classes of materials are subject to some degree of deterioration. Since the dissolved ozone concentration under normal operation is most closely simulated by the side stream, it appears that the two-component polyurethane would provide the best operational characteristics. Furthermore, best design practices, given the potential for expansion joint maintenance requirements under the given environmental conditions, would be to locate expansion joints in areas outside of the ozone environment such as in pipe galleries and in between bulk heads.

One final consideration for this concrete structure is that fact that test results indicate that structural adhesives are subject to deterioration or at least bond deterioration. This leaves us few options in the maintenance department to perform crack repairs. Particular attention should be placed on engineering details to minimize the potential for structural cracking.

Now let us consider piping and wall penetrations. Wall penetrations for large diameter pipe similar to that which will be used for gas collection headers generally consists of a pipe spool with a water stop welded to the outside diameter. The spool is cast into the concrete structure during construction. Since the piping is generally metallic and significant welding is required for fabrication, the austenitic grades of stainless steel lend themselves to this application given the corrosion experienced by carbon steel which would be the other alternative. Furthermore, the austenitic grades of stainless show the most promise for the fabrication of gates and valves which would be used to isolate the reactor vessel. In terms of flange gaskets and gasketing in general, Viton-A and EPDM appear to have the best performance of the materials that were evaluated.

The reactor vessel may need to be evacuated from time to time requiring an under-drain system. Plastic piping may be sufficient for this application given the test results. Although the test results indicated that plastic materials are resistant to ozone, caution should be exercised in the use and specification of plastic materials in contact with ozone environments. Plastic materials generally contain anti-oxidants, plasticizers, processing aids and other additives. These additives and the plastics themselves may be susceptible to ozone attack and degrade in time.

Often times, protective coatings are used in conjunction with steel structures. Test results indicate that no coatings are resistant to ozone in the long run and should not be considered. Alternative metal alloys would be the option of choice.

It is our hope that this discussion has shed some light on material selection issues in ozone contactor design and the lack of information on long-term durability. Furthermore, it should be noted that the results contained in this study are only applicable to the environment under consideration. Changes to process parameters such as the use of pH reduction as a process control strategy may impact materials differently. The mechanisms by which degradation takes place are not clearly understood and therefore degradation resistance should not be implied by the results of this study.