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# Comparison of Fiberglass and Other Polymeric Well Casings, Part I: Susceptibility to Degradation by Chemicals

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## Abstract

Previous research has shown that the most commonly used well casing materials—stainless steel, polyvinyl chloride (PVC), and polytetrafluoroethylene (PTFE)—are not suited for all monitoring environments and applications. This study is part of a series of experiments that were conducted to determine the suitability of four other polymeric well casing materials—acrylonitrile butadiene styrene (ABS), fluorinated ethylene propylene (FEP), fiberglass-reinforced epoxy (FRE), and fiberglass-reinforced plastic (FRP)—for use in ground water monitoring wells. In these studies, these four materials were compared with two other commonly used polymeric well casings, PVC and PTFE. Part I of these studies examines the resistance of these materials to degradation by chemicals. Future reports will consider sorption and leaching of organic and metal contaminants.

In this study, the six materials were exposed to 28 neat organic compounds (including one acid) and to extremely acidic and alkaline aqueous solutions for up to 112 days. This was done to simulate the most aggressive environments to which monitoring well casings may be exposed. The casings were observed for changes in weight and signs of physical degradation (swelling, softening, deterioration, or dissolution).

The two fluorinated polymers (FEP and PTFE) were not degraded by any of the test chemicals. Among the nonfluorinated products tested, FRE was the most inert. Three organic chemicals caused the glass fibers to separate, and two organic solvents caused weight gains exceeding 10 percent. ABS was the most readily degraded material tested. By the end of the study, only the acid and alkaline solutions had little effect on ABS. FRP was more severely degraded by the organic chemicals than FRE but was less affected than PVC. FRP and FRE lost weight when exposed to the highly acidic conditions.

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## Introduction

Ideally any material used in well casings and screens for ground water monitoring wells should be strong enough to remain intact once installed in the well, should resist degradation by the environment, and should not affect contaminant concentrations in samples by leaching or sorbing organics or metals. Recent draft RCRA guidance by the U.S. Environmental Protection Agency (U.S. EPA 1992) acknowledges that none of the most commonly used well casing materials in ground water monitoring—polyvinyl chloride (PVC), polytetrafluoroethylene (PTFE), or stainless steel—is suitable for all monitoring applications. Physical strength considerations limit the useful depth for PTFE and, to a lesser extent, PVC (Nielsen and Schalla 1991). PVC is degraded by several neat organic solvents (Plastics Design Library 1994a), and high concentrations of these chemicals in aqueous solutions can also degrade PVC (Berens 1985; Vonk 1985, 1986; Parker and Ranney 1994a, 1995, in press). While stainless steel is not subject to solvation by organic solvents, it is subject to corrosion by a variety of environmental conditions (Aller et al. 1989). Also, previous studies by this laboratory (Hewitt 1989, 1992, 1994; Parker et al. 1990; Parker and Ranney 1994b) and others (Reynolds and Gillham 1985; Gillham and O'Hannesin 1990; Reynolds et al. 1990) have shown that none of these materials are inert with respect to sorption and leaching of organic contaminants and metals.

Therefore, we undertook a series of studies to assess the suitability of four other candidate well casing materials with respect to these issues. The materials we tested were acrylonitrile butadiene styrene (ABS), fluorinated ethylene propylene (FEP), fiberglass-reinforced epoxy (FRE), and fiberglass-reinforced plastic (FRP).

ABS is a terpolymer of acrylonitrile, butadiene, and styrene. A wide range in properties can be achieved by varying the ratio of these monomers or by using various additives (Sax and Lewis 1987). Ratios vary with the formulation but typically run 20 to 30 percent acrylonitrile, 20 to 30 percent butadiene, and 40 to 60 percent styrene. FEP is a fluoropolymer and a copolymer of tetrafluoroethylene and hexafluoropropylene. It is similar to PTFE in its chemical and physical properties, although it has a slightly higher coefficient of friction (Sax and Lewis 1987). Fiber-reinforced plastics are products in which a polymeric matrix is combined with reinforcing fibers. Typical fibers include glass, carbon-graphite, or aramid (or aromatic polyamides) (Charrier 1990). The products used in these studies contained glass fibers. The polymeric matrices used in fiber-reinforced plastics are primarily of the thermosetting type and include unsaturated polyesters, vinylesters, and epoxides (Charrier 1990). The FRE used in these studies was composed of 75 percent silica glass and 25 percent closed molecular epoxy, which we believe was manufactured from bisphenol-A-type epoxy resins cured with methyl tetrahydrophthalic anhydride (Cowgill 1988). According to the manufacturer's literature, the FRP used in this study consisted of 70 percent fiberglass and 30 percent polyester resin, by weight.

This study focuses on the ability of these materials to resist degradation by chemicals. When we initiated this study, information on the ability of some of these materials to resist chemical degradation was incomplete. Some information was provided by the manufacturers, while other sources of information were the Cole-Parmer catalog (1992) and the Nalge catalog (1994). The most complete source of information is a two-volume series recently published by the Plastics Design Library (1994a,b), which provides information on the chemical resistance of PTFE, FEP, ABS, and PVC. This document also contains some information on the chemical resistance of bisphenol A epoxy resin and a number of polyesters.

This information indicates that FEP (Nalge 1994; Plastics Design Library 1994a) and PTFE (Nalge 1994; Cole-Parmer 1992; Plastics Design Library 1994a) have excellent resistance to chemical attack by corrosive reagents or dissolution by organic solvents. On the other hand, PVC is known to be degraded by several neat organic solvents (Cole-Parmer 1992; Plastics Design Library 1994a; Nalge 1994), including low-molecular-weight ketones, aldehydes, amines, and chlorinated alkanes (Barcelona et al. 1984). The Plastics Design Library (1994a) reported findings for several formulations of PVC, and the Nalge Co. (1994) differentiated between flexible and rigid PVC. In both these publications, instances can be found where the ratings for a particular chemical varied for different formulations of the same polymer. ABS is also reported to be severely degraded by a large number of organic solvents, which include several ketones, chlorinated alkanes, and alkenes, as well as several hydrocarbons such as fuel oils, gasoline, and kerosene (Cole-Parmer 1992; Plastics Design Library 1994a). Again for some chemicals, the Plastics Design Library (1994a) reported the response of ABS varied depending upon the formulation tested. According to the manufacturer, FRE is impervious to gasoline, hydrocarbon products, and most solvents and additives. Information given by Cole-Parmer (1992) for an unspecified "epoxy" and by the Plastics Design Library (1994b) for a bisphenol A epoxy appears to support this claim for hydrocarbons but not for all solvents. They reported that epoxy is seriously degraded by chloroform, dimethyl formamide, methyl ethyl ketone, and TCE, among others. The manufacturer of FRP makes no claims about its resistance to organic solvents. Since the manufacturer did not specify which polyester was used in its product, we cannot discuss its chemical resistance except in generic terms. Generally, polyesters are resistant to corrosive chemicals and solvents (Sax and Lewis 1987; Plastics Design Library 1994a). However, Fuchs (1989) lists at least one solvent for each polyester listed.

Since we did not know the specific formulations used in several of these well casings and since the chemical resistance of these polymers can vary with formulation, especially FRE and FRP where glass fibers are added to the polymer matrix, we decided to compare the chemical resistance of these materials by subjecting them to a variety of neat (undiluted) organic chemicals and to extremely acid and alkaline conditions.

## Materials and Methods

Six types of 2-inch-diameter (5 cm) well casing or pipe were used in this study: PVC, PTFE, FEP, ABS, FRE, and FRP. For PVC, PTFE, FRP, and FRE, we used well casings manufactured specifically for ground water monitoring. We were unable to find a manufacturer that made FEP well casings but did find one that made "pipe for sampling ground water." When we tried to purchase the ABS well casing, we found that it was no longer being manufactured. As a result, we purchased waste and vent pipe. Test pieces measuring approximately 1 $cm^2$ were cut from each pipe material. Special care was taken to eliminate contamination from grease or oil during the cutting process. The cutting process fractured some of the edges on the fiberglass test pieces, but these pieces were not used in this study.

The test pieces were cleaned by placing them in 2 percent solutions of detergent (Liquinox) and deionized water and stirring for five minutes, then rinsing repeatedly with deionized water until there was no evidence of sudsing. The pieces were drained and rinsed with several additional volumes of deionized water, drained, and then left on paper towels to air dry.

Each test piece was weighed to ± 0.0001 g and placed in a 22-mL borosilicate glass vial. Twenty-eight neat organic compounds (including one acid) and 25 percent solutions of hydrochloric acid (7 m) and sodium hydroxide (6 m) (Table 1) were used in this study. The organic solvents that were tested included six hydrocarbons (aliphatic and aromatic), 10 chlorinated solvents (aliphatic and aromatic), seven oxygen-containing compounds (ketone, alcohol, aldehyde, or ether), and four nitrogen-containing compounds. Most of the test chemicals were U.S. EPA priority pollutants. Five mL of test chemical was added to each vial, completely covering the test specimens. The vials were then sealed with Teflon®-lined plastic caps. The samples were stored at room temperature. There were no replicate samples in this study. The test pieces were evaluated for changes in weight and other changes after one, seven, 14, 21, 28, 56, and 112 days of contact. On a sampling day, each test piece was removed from the vial using stainless steel forceps, blotted with a paper towel, and allowed to air dry for approximately one minute before weighing. Weight gain or loss was used as one measure of physical change. To determine softening, the test pieces were squeezed with forceps and checked for signs of indentation. An untreated test piece was used as a reference.

### Table 1

**Percent Weight Gain at 112 Days of Exposure or Number of Days to Failure in Parenthesis***

| Chemical | PTFE | FEP | FRE | FRP | PVC | ABS |
|---|---|---|---|---|---|---|
| **Hydrocarbons (aliphatic and aromatic)** | | | | | | |
| Benzene | 0.4 | 0.3 | 0.0 | 0.8 | 48.7 | (1)[c] |
| Gasoline (93 octane, unleaded) | 0.3 | 0.2 | −0.1 | 0.1 | 0.1 | 61.9 |
| Hexane (85 percent N-hexane) | 0.4 | 0.2 | −0.1 | 0.0 | −0.1 | 15.1 |
| Kerosene (K-1) | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 | 8.9 |
| Toluene | 0.2 | 0.2 | 0.0 | 0.9 | 51.4 | (1)[c] |
| *o*-xylene | 0.1 | 0.1 | −0.1 | 0.2 | 65.7 | (7)[c] |
| **Chlorinated Solvents (aliphatic and aromatic)** | | | | | | |
| Bromochloromethane | 0.7 | 0.6 | 26.2 | (7)[b] | (1)[c] | (1)[c] |
| Carbon tetrachloride | 0.6 | 0.4 | 0.0 | 0.2 | 0.1 | 317.2 |
| Chlorobenzene | 0.3 | 0.3 | 0.2 | 7.8 | 159.8 | (1)[c] |
| Chloroform | 1.0 | 0.8 | 7.3 | (7)[b] | 223.9 | (1)[c] |
| 1,2-dichlorobenzene | 0.2 | 0.1 | 0.1 | 1.1 | 217.7 | (1)[c] |
| 1,2-dichloroethane | 0.4 | 0.3 | 3.1 | (21)[b] | (14)[c] | (1)[c] |
| *trans*-1,2-dichloroethylene | 1.4 | 1.2 | 8.1 | (14)[b] | 56.3 | (1)[c] |
| Methylene chloride | 0.9 | 0.8 | 15.6 | (1)[b] | (7)[c] | (1)[c] |
| Tetrachloroethylene | 0.9 | 0.6 | 0.0 | 0.5 | 1.7 | 251.2 |
| Trichloroethylene | 1.3 | 1.1 | 0.3 | (28)[b] | 70.9 | (1)[c] |
| **Oxygen-Containing Compounds (ketone, alcohol, aldehyde, or ether)** | | | | | | |
| Acetone | 0.3 | 0.2 | 2.7 | 5.6 | 157.8 | (1)[c] |
| Benzaldehyde | 0.0 | 0.0 | 0.3 | 1.3 | (7)[c] | (1)[c] |
| Benzyl alcohol | 0.0 | 0.0 | 0.1 | 0.5 | 0.1 | (1)[c] |
| Cyclohexanone | 0.0 | 0.0 | −0.1 | 0.1 | (1)[c] | (1)[c] |
| Methyl alcohol | 0.0 | 0.0 | 7.7 | 1.9 | 0.4 | 27.8 |
| Methyl ethyl ketone | 0.3 | 0.2 | 3.0 | 4.8 | (7)[c] | (1)[c] |
| Tetrahydrofuran | 0.3 | 0.3 | 3.3 | (28)[b] | (1)[c] | (1)[c] |
| **Nitrogen-Containing Compounds** | | | | | | |
| N-butylamine | 0.2 | 0.1 | (7)[a] | (21)[b] | (21)[c] | (1)[c] |
| Diethylamine | 0.5 | 0.3 | 2.0 | 3.5 | 31.8 | 112.8 |
| Dimethylformamide | 0.0 | 0.1 | (14)[a] | 8.3 | (1)[c] | (1)[c] |
| Nitrobenzene | 0.1 | 0.0 | 0.4 | 1.0 | (7)[c] | (1)[c] |
| **Acids and Bases** | | | | | | |
| Acetic acid (glacial) | 0.4 | 0.3 | (56)[a] | 1.5 | 0.4 | 76.8 |
| Hydrochloric acid (25 percent) | 0.0 | 0.0 | −4.7 | −5.0 | 0.3 | 1.2 |
| Sodium hydroxide (25 percent) | 0.0 | 0.1 | 0.2 | 1.5 | 0.1 | 0.9 |

*Samples were tested on days one, seven, 14, 21, 28, 56, and 112

[a] Fibers within product separated

[b] Fiberglass sheets separated

[c] Dissolved or disintegrated upon swelling

Signs of swelling and other forms of deterioration were also noted. After weighing, the test piece was returned to its vial and the vial was recapped.

## Results and Discussion

### Research Findings

Some test pieces were seriously degraded by exposure to some of the neat test chemicals. In those instances, Table 1 shows the number of days when serious degradation, such as deterioration or dissolution, was observed. For the test pieces that were not seriously degraded by exposure to the chemicals, Table 1 shows the final percent weight gains after 112 days of contact. The complete data set, including the changes with time, can be found in Ranney and Parker (1995).

As expected, we did not observe any softening, swelling, or decrease in strength in any of the FEP and PTFE samples. However, these materials did show slight weight gains (~1 percent) when exposed to five organic chemicals (chloroform, *trans*-dichloroethylene, methylene chloride, tetrachloroethylene, and trichloroethylene).

Among the nonfluoropolymers, FRE appeared to be the least affected material. Three organic chemicals (acetic acid, n-butylamine, and dimethyformamide) caused separation of the glass fibers after one to eight weeks. Samples exposed to bromochloromethane and methylene chloride had the largest weight gains, 26 percent and 16 percent, respectively. Eight other chemicals caused weight gains of 1 to 10 percent. The sample exposed to the hydrochloric acid solution lost weight (~5 percent), most likely a result of loss of the epoxy resin, while the alkaline solution had no effect. None of the FRE test pieces appeared to swell or soften, even the samples with the largest weight gain. Some fraying of the edges was observed on some test pieces, but this may have been initiated by the cutting process. In general, FRE did not appear to be affected by the aliphatic or aromatic hydrocarbons.

FRP was more severely degraded than the three previous materials. Eight organic solvents (bromochloromethane, n-butylamine, chloroform, 1,2-dichloroethane, *trans*-1,2-dichloroethylene, methylene chloride, tetrahydrofuran, and trichlorethylene) delaminated it (i.e., the fiberglass sheets separated). This occurred within the first 24 hours for methylene chloride and within one to four weeks for the other solvents. Eleven other chemicals (including the glacial acetic acid and the sodium hydroxide solution) caused weight gains of 1 to 10 percent, but none of these chemicals caused noticeable swelling or softening. Again, some of the test pieces had frayed edges, which may have been the result of cutting the test pieces. As with FRE, the hydrochloric acid solution caused a slight loss in weight (5 percent). In general, FRP appeared to be unaffected by hydrocarbons and the nonpolar chlorinated solvents.

PVC appears to be much more readily degraded than the previously discussed materials. By the end of the study, 10 chemicals dissolved or so softened the PVC that the test pieces disintegrated and could not be weighed. Four chemicals had this effect within the first day. Ten other chemicals appeared to soften PVC, and four of those chemicals caused weight gains that exceeded 100 percent. Only nine of the 30 chemicals used in this study had little or no effect on PVC. These chemicals were the neat organic acid, the acid and hydroxide solutions, the two alcohols, three hydrocarbons (gasoline, hexane, and kerosene) and carbon tetrachloride. In general, PVC is especially susceptible to degradation by polar, nonhydrogen-bonded solvents (Leggett 1994).

ABS was by far the most readily degraded polymer. After only one day, 19 of the 30 chemicals tested either dissolved the ABS or caused it to disintegrate. Four other chemicals caused softening or swelling of the test piece on the first day. By the end of the study, only the acid and alkali solutions had little effect. While ABS is susceptible to organic solvents in general, Leggett (1994) concluded that these data show that ABS is especially susceptible to polar solvents. Clearly ABS is a poor choice where exposure to neat organic solvents may be involved.

### Comparison of CRREL Findings with Other Published Ratings

Table 2 compares our findings (Cold Regions Research and Engineering Laboratory) with chemical resistance ratings by Plastics Design Library (PDL) (1994a,b), Cole-Parmer Co. (1992), and Nalge Co. (1994). We developed the classification scheme outlined at the bottom of Table 2 so that our data could be more easily compared with the other chemical resistance ratings.

Generally there was good agreement between the other ratings and ours for PTFE and FEP, except for the Cole-Parmer ratings for PTFE exposed to diethylamine and dimethylformamide, which were much lower than the others. Since these two materials are inert to most chemicals, it is not surprising there is little variability between the various ratings.

For ABS, the most readily degraded material, there was also generally good agreement between the Cole-Parmer and PDL ratings and ours. However, there was a wide range in the values reported by the PDL for several chemicals: hydrocarbons (hexane, gasoline, kerosene), glacial acetic acid, and carbon tetrachloride. This can make it difficult to determine the suitability of a material for a particular application, especially if only one rating table is used.

For PVC, there was major disagreement among the four rating systems for five (or 17 percent) of the chemicals tested (glacial acetic acid, benzyl alcohol, chlorobenzene, gasoline, and tetrachloroethylene). In all cases the Cole-Parmer ratings were lower than ours. It appears that these discrepancies can be explained by differences between flexible and rigid PVC. In the instances where Nalge ratings were available, their rat-

## Table 2

## Comparison of CRREL Chemical Resistance Ratings with Those Given In Cole-Parmer and Nalge Catalogues and the Plastics Design Library

| | PTFE | | | | FEP | | | FRE | | | FRP | | PVC | | | | | ABS | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Chemical** | **C-P[1]** | **PDL[2]** | **CRREL** | **Nalge[3]** | **PDL** | **CRREL** | **Nalge** | **C-P** | **PDL** | **CRREL** | **PDL** | **CRREL** | **C-P** | **PDL** | **CRREL** | **Nalge** | | **C-P** | **PDL** | **CRREL** |
| | | | | | | | | *epoxy* | bisphenol | | polyester | | | | | rigid | flexible | | | |
| **Hydrocarbons (aliphatic and aromatic)** | | | | | | | | | | | | | | | | | | | | |
| Benzene | A | 9 | A | E | 9 | A | E | C1 | 8 | A | 9* | A | C1 | 3* | D | N | N | D | 0-2 | D |
| Gasoline (93 octane, unleaded) | A | 8 | A | E | 8 | A | E | A2 | 8 | A | 9* | A | C2 | 7-8 | A | G | N | D | 1-9 | D |
| Hexane | A | 8 | A | E | 8 | A | E | A | 8 | A | – | A | B2 | 3-8 | A | G | N | D | 2-9 | C |
| Kerosene (K-1) | A | – | A | E | – | A | E | A | 8 | A | – | A | A2 | 8* | A | E | N | D | 4-8 | C |
| Toluene | A | 9 | A | E | 9 | A | E | B1 | 8 | A | 9* | A | D | 3* | D | N | N | D | 0-4 | D |
| *o*-xylene | A | 8 | A | E | 8 | A | E | A | 8 | A | 9* | A | D | 3* | D | N | N | D | 0* | D |
| Chlorinated Solvents (aliphatic and aromatic) | | | | | | A | | | | | | | | | | | | | | |
| Bromochloromethane | – | – | A | – | – | A | – | – | – | C | – | D | – | – | D | – | – | – | – | D |
| Carbon tetrachloride | A | 8 | A | E | 8 | A | E | A1 | 8 | A | 9* | A | D | 3-8 | A | G | N | D | 0-5 | D |
| Chlorobenzene | B | – | A | E | – | A | E | C1 | – | A | 9* | C | D | 3* | D | N | N | D | 0-2 | D |
| Chloroform | A1 | 8 | B | E | 8 | A | E | C1 | 2 | C | 9* | D | D | 3* | D | N | N | D | 0-2 | D |
| 1,2-dichlorobenzene | A | – | A | E | – | A | E | A | – | A | – | B | D | 3* | D | N | N | D | 0-2 | D |
| 1,2-dichloroethane | A1 | – | A | E | – | A | E | D | – | B | – | D | D | – | D | F | N | D | – | D |
| *trans*-1,2-dichloroethylene | – | – | B | – | – | B | – | – | – | C | – | D | – | – | D | – | – | – | – | D |
| Methylene chloride | A | – | A | E | – | A | E | A | 2 | C | 9* | D | D | 3* | D | N | N | D | 2* | D |
| Tetrachloroethylene | A | 8 | A | – | 8 | A | – | – | 8 | A | – | A | D | – | B | – | – | – | 2* | D |
| Trichloroethylene | A | 8 | B | E | 8 | B | E | C1 | 2 | A | 9* | D | D | 3* | D | N | N | D | 0-2 | D |
| Oxygen-Containing Compounds (ketone, alcohol, aldehyde, or ether) | | | | | | | | | | | | | | | | | | | | |
| Acetone | A | 8-9 | A | E | 9 | A | E | B1 | – | B | 9* | C | D | 3* | D | N | N | D | 0-2 | D |
| Benzaldehyde | A1 | – | A | E | 8 | A | E | D | – | A | – | B | D | 3* | D | N | N | B | 2 | D |
| Benzyl alcohol | A | 8 | A | E | 8 | A | E | C | – | A | – | A | D | – | A | G | F | D | 2 | D |
| Cyclohexanone | A | – | A | E | – | A | E | C | 8 | A | – | A | D | 3* | D | N | N | D | 0-2 | D |
| Methyl alcohol | A | 8 | A | E | 8 | A | E | B1 | 8 | C | 9* | B | A1 | 8-9 | A | E | F | D | 1-3 | C |
| Methyl ethyl ketone | A | 8 | A | E | 8 | A | E | C1 | 2 | B | 9* | B | D | 3* | D | N | N | D | 0-2 | D |
| Tetrahydrofuran | A | – | A | E | – | A | E | A | 8 | B | – | D | D | 3* | D | N | N | – | 0* | D |
| Nitrogen-Containing Compounds | | | | | | | | | | | | | | | | | | | | |
| N-butylamine | A2 | 8 | A | – | 8 | A | – | B2 | 2 | D | – | D | D | – | D | – | – | – | – | D |
| Diethylamine | D | – | A | E | – | A | E | A | – | B | – | B | D | – | D | N | N | D | – | D |
| Dimethylformamide | D | 8 | A | E | 8 | A | E | D | 2 | D | 7* | C | D | – | D | F | N | D | 0* | D |
| Nitrobenzene | A | 8 | A | E | 8 | A | E | C1 | 2 | A | – | A | D | 3* | D | N | N | D | 2 | D |
| Acids and Bases | | | | | | | | | | | | | | | | | | | | |
| Acetic acid (glacial) | A | 8 | A | – | – | A | – | B1 | 2 | D | 9* | B | D | 0-8 | A | – | – | D | 0-8 | D |
| Hydrochloric acid (25% w/v) | A | 9(20%) | A | E | 9(10%) | A | E | A1 | 7 | B | 9*(20%) | B | A2 | 8-9(30%) | A | E | E | A | 9* | B |
| Sodium hydroxide (25% w/v) | A | 9(10%) | A | – | 9(10%) | A | – | A | 8 | A | 9* | B | A | 8*(30%) | A | – | – | B | 9* | A |

[1] **Cole-Parmer chemical resistance ratings**
A No effect–excellent
B Minor effect–good
C Moderate effect–fair
D Severe effect–not recommended
1 satisfactory to 22°C
2 satisfactory to 48°C

[2] **Plastics Design Library ratings (0 to 9) (23°C)**
0 Solvent dissolved polymer
9 No change
* Only one material tested

[3] **Nalge chemical resistance ratings (20°C)**
E No damage after 30 days
G Little or no damage after 30 days
F Some effect after 7 days
N Not recommended for continuous use

**CRREL chemical resistance ratings from experimental observations**
A Excellent. Any chemical with little or no effect, i.e., the change in weight was 1 percent or less.
B Good. Any chemical that had only a minor effect, i.e., there was no observable effect except for a slight change in weight (from 1 to 5 percent).
C Moderate effect. Those chemicals that caused more than a 5 percent change in weight with no other observable changes.
D Unacceptable. Any chemical that caused the material to swell, soften, dissolve, delaminate, or lose particles.

ings for flexible PVC agreed with the Cole-Parmer ratings, while their ratings for rigid PVC agreed with our findings for rigid PVC casing. For glacial acetic acid, carbon tetrachloride, and hexane, the PDL ratings ranged from quite low to fairly high, indicating that some formulations of PVC are more resistant than others.

Only limited comparisons can be made for FRP since the only ratings available were the PDL ratings for approximately half of the chemicals tested. However, these ratings did not agree well with our findings. Approximately 30 percent of the PDL ratings were two or more grade levels higher than ours, and another ~40 percent were at least one grade level higher. The PDL ratings may have been higher because these tests were run for only one day, while ours were run for 112 days. In addition, the PDL ratings were for one type of polyester, which may be quite different in its properties than the one used to fabricate the FRP casings.

For the FRE, there were many discrepancies between the Cole-Parmer ratings, the PDL ratings, and ours (for approximately one-third of the chemicals). In eight instances, the values given by Cole-Parmer were lower than ours. For those compounds where PDL ratings were also available, half of the PDL ratings agreed with our findings, and half did not. In addition, two of the Cole-Parmer ratings were substantially higher than ours, but in both of these cases the PDL ratings agreed with ours. It is understandable that the Cole-Parmer ratings would differ from ours given that their ratings were for some unknown "epoxy," while the PDL ratings were for a bisphenol-A-type epoxy, which is either identical or similar to the epoxy that was used in these FRE casings.

These comparisons show that chemical resistance rating tables are useful and accurate for the fluoropolymer casings, which are resistant to almost all chemicals. These ratings also indicate that ABS is subject to degradation by almost all organic solvents. For the other materials, serious differences may exist between a published rating and the true chemical resistance of a well casing. These differences can be reduced by making certain the formulation of the polymer tested is either similar or identical to the formulation used in a well casing. Thus, reasonably reliable data can be found for PVC as long as a rigid formulation is tested. However, it would be prudent to test the fiberglass materials against any chemicals that were not tested in this paper.

## Conclusions and Recommendations

It appears that all the materials have good or excellent resistance to alkaline conditions. With respect to exposure to acidic conditions, FEP, PTFE, and PVC have excellent resistance, while ABS, FRE, and FRP were slightly affected.

Based on our findings and those found in other chemical resistance rating tables, we would rank the resistance of these materials to organic solvents, from greatest to least resistance, as follows: FEP=PTFE> FRE> FRP> PVC> ABS. This ranking should be used only as a general guide, not as a rule. Resistance of the nonfluoropolymers can vary with the formulation. It may be prudent to test a casing with the particular chemical if the resistance data differ between rating tables or within the same rating table, or if there are not any data for a particular chemical and casing material (especially likely for the fiberglass casings).

These tests were conducted to determine the ability of these materials to withstand exposure to extreme environments, such as neat solvents or strong acids or alkalis for 112 days. There may be additional effects by some chemicals after prolonged exposure. However, most water wells contain low ppm or ppb levels of organic contaminants and not pure product. This study did not address the effects that aqueous solutions of organic solvents have on these materials or the effects that these materials have on low concentrations of organic solutes. The ability of these six materials to sorb organic solutes (at low ppm levels) will be the focus of Part II of this report. Additional information is available elsewhere on the effects of high concentrations of PVC solvents on rigid PVC (Berens 1985; Vonk 1985, 1986; Parker and Ranney 1994a, 1995, 1996). The findings of this study could be applied in a similar manner to determine the effects of high concentrations of chemicals that are able to degrade FRE, FRP, or ABS.

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