

# Consider Using Fluoropolymers in Biological Applications

**LAURI JENKINS AND SHARON LIBERT**  
DU PONT FLUOROPOLYMER SOLUTIONS

**VICTOR LUSVARDI**  
COWIE TECHNOLOGY

Even with the use of costly corrosion-resistant alloys, metal contamination continues to occur in the biologics industry, thus reducing product yield and activity. Fluoropolymers are emerging as a viable solution to this problem.

**T**HE BIOLOGICS INDUSTRY IS INVESTING SIGNIFICANT capital in switching from 316L stainless steel (SS) to more costly corrosion-resistant metal alloys, such as Ni-based C276 and Fe-based AL6XN. While this investment is reducing corrosion problems, it is not eliminating the contamination from metal ions extracting into the process stream.

Stainless steel requires expensive passivation and electropolishing steps to meet validation. Electropolishing smooths the surface by reducing the height of aspirates, but does not remove the crannies at the base of these peaks and can even create pits that lead to increase biofilm adhesion (1).

In contrast, the metal contamination from fluoropolymers is nearly undetectable. Fluoropolymers also have greatly reduced biofilm adhesion relative to conventional electropolished 316L SS (1). These qualities should translate into reduced clean-in-place (CIP) operations, maintenance costs, and time-to-validation, as well as improved product yields and activity.

The semiconductor industry has already made the move to fully fluorinated polymers as materials of construction. This move is based on the need for high purity, high physical integrity and chemical resistance. It is a logical progression that the biologics industry will also move to using fluoropolymers as the preferred materials of contact in their systems.

This article discusses corrosion and extraction experiments and results conducted on various metal alloys (316L, AL6XN, C276 and I625) vs. high-purity poly(tetrafluoroethyl-co-perfluoropropylvinylether) (HP-PFA), at different temperatures and

exposure times. Two experimental methods were used. The first one was a trace-metal extraction technique developed for the semiconductor industry to determine metal contamination levels from process components. The second, was the ASTM G48-00 method — Pitting and Crevice Corrosion Resistance of Stainless Steels and Related Alloys by Use of Ferric Chloride Solution (2).

**Test Method 1** — The exposure medium was a 15 wt% aqueous solution of sodium chloride (NaCl) that was adjusted to a pH of 2 by addition of hydrochloric acid (HCl). Metal test coupons were obtained from Metals Samples Co. (3). The dimensions of each metal coupon were 2 × 2 × 0.125 in. Metal samples were used from two different lots. 24-h and 72-h tests were done with samples from the same metal lots. Some of the samples for the 168-h test were from different metal lots.

The PFA test coupons were cut from extruded-film Teflon PFA HP fluoropolymer. The dimensions of each PFA coupon was 2 × 2 × 0.060 in. Table 1 shows the elemental compositional analysis of each metal lot used in this study (data provided by the Metals Samples Co.).

Each test coupon was immersed into the 30-mL test solution described above for a time period of 24, 72 and 168 h and maintained at a temperature of 40°C. The initial salt solution was analyzed to establish the absence of metals Cr, Ni, Mo, Mn and Fe. After completion of the determined exposure period, the metal contamination level in the test solution was measured and reported as ng/cm<sup>2</sup> of coupon. A blank control of the test solution was run and all results were blank subtracted. The metal contamina-

# Materials

tion in the salt solution was determined by high resolution inductively coupled plasma (ICP), mass spectroscopy (MS), or ICP-atomic emission spectroscopy (AES). Metals analyzed for and data was obtained for Al, Sb, As, Ba, Be, Bi, B, Cd, Ca, Cr, Co, Cu, Ga, Ge, Au, Fe, Pb, Li, Mg, Mn, Mo, Ni, Nb, K, Ag, Sr, Ta, Tl, V, Zn and Zr. The metals showing the highest concentration in the extraction solutions are reported in this article. The coupon immersion and metal analysis was performed in a cleanroom environment. The CHEMTRACE Co. (4) performed all testing and analyses.

The alloy lots for all but the AL6XN and C276 samples changed for the 168 h (7 day) extractions. This was due to sample availability. All extractions at 168 h were run in duplicate. The 24- and 72-h test results were from single samples. PFA was run only at the 168-h extraction time, in duplicate.

### Test Method 2 — ASTM G48-00

Method D (1) was developed for the comparison of stainless steels and related alloys as to their resistance to the initiation of pitting and crevice corrosion in aqueous chloride-containing environments.

These methods are considered accelerated compared to most natural environments. Method D is for the determination of critical crevice temperature by the application of two crevice washers on each side of the sample under torque. For method details, refer to *Ref. 2*.

The ferric chloride test solution was prepared to give an aqueous solution of 6 wt% FeCl and 1 wt% HCl. The test coupons were fitted with multiple crevice washers on both sides of the coupon and torqued to 20 in/lb of force. The test coupons were suspended in the salt solution for 72 h at a constant temperature and then examined for crevice corrosion. If the sample did not show evidence of crevice corrosion, new samples were prepared and

the temperature was increased by 10°C for another 72-h test. Crevice corrosion is defined as the presence of local attack of 0.024-mm depth or greater. This local attack is observed visually and by optical microscopy (20× magnification) and documented by micrographs as per the ASTM (2). The corrosion testing began at 25°C for the 316L stainless steel coupon and 35°C for all other alloys.

Tables 2 and 3 show the results of the major ions extracted from the metal coupons and the PFA sample at 1, 3 and 7 days of exposure to a solution of 15 wt% NaCl and pH of 2.0. The

**Table 1. Primary elemental composition of metal alloy samples used in this study.**

Alloy	316L		AL6XN	I625		C276	
	W584	T557	U362	M938	H371	U346	W025
Lot #							
Element							
Fe	68.73	68.81	22.87	3.42	3.72	5.70	5.65
Ni	10.25	10.14	23.88	61.55	61.13	57.00	57.23
Cr	16.85	16.24	20.47	21.67	21.83	16.20	15.38
Mo	2.04	2.07	6.26	9.05	9.16	16.20	15.67

**Table 2. Seven-day metal and PFA extraction results\* (ng of metal/cm<sup>2</sup> of coupon).**

Metal	I625	C276	AL6XN	316L	PFA	Detection Limit
Element	Average concentration value for 168 h (ng/cm <sup>2</sup> )					
Cr	190	260	375	950	B/D**	10
Cu	18	51	67	94	B/D	10
Fe	405	595	2,750	8,550	B/D	10
Mn	4.2	21.5	17	205	B/D	1
Mo	98.5	615	145	94	B/D	1
Ni	1,200	2,600	775	845	B/D	10

\* Results are the average of duplicate samples. \*\* B/D = Below detection limit

**Table 3. One- and three-day metal and PFA extraction results (ng of metal/cm<sup>2</sup> of coupon).**

Metal	I625		C276		AL6XN		316L		PFA	
	24	72	24	72	24	72	24	72	24	72
Element	Concentration in extraction solution (ng/cm <sup>2</sup> )*									
Cr	13	65.5	23.5	78	16	24.5	300	395	B/D	B/D
Cu	79.5	94.5	80	59	48	58.5	55.5	76	B/D	B/D
Fe	100	110	325	215	730	760	3,300	3,150	B/D	B/D
Mo	28	43.5	145	150	35	33	48	45.5	B/D	B/D
Ni	320	490	655	775	195	200	365	345	B/D	B/D
Total	541	804	1,229	1,277	1,024	1,076	4,069	4,012	0	0
ng/24h exposure**	8.7E+07		1.99E+08		1.66E+08		6.58E+08		0.00	

\* Detection limits are the same as those listed in Table 2.

\*\* For a 2,000-L tank with a radius-to-height ratio of 1:2, based on 24-h extraction data.

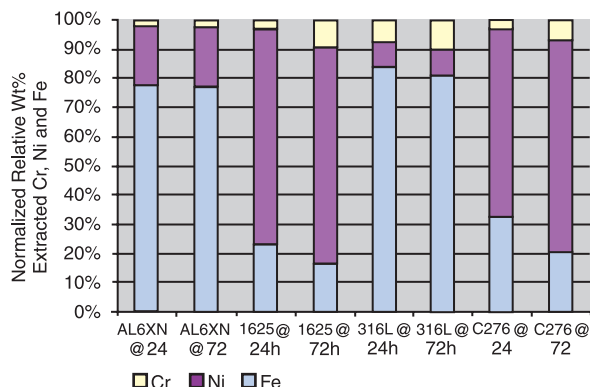


Figure 1. Normalized relative % of Cr, Ni, and Fe extracted from SS alloys in test solution at 24 and 72 hours.

24- and 72-h results were analyzed separately from the 168-h results. This was due to the use of a different set of metal coupon lots for the 168-h testing. The general trends in the data (relative results) are the same within each data set, the magnitudes do vary and more testing needs to be done before both sets could be compared directly.

The 316L stainless steel showed crevice corrosion at 35°C, while the ALX6N and the I625 showed crevice corrosion at 60°C. The C276 showed crevice corrosion at 80°C. The PFA perfluoropolymer showed no indication of crevice corrosion at 80°C. The temperature was raised to 85°C and the test was extended to an additional exposure of one week in the test solution for the PFA coupon. At the end of the additional week the PFA coupon showed no crevice corrosion or discoloration.

### The case for fluoropolymers

Referring to Tables 2 and 3, the extraction data indicates that even corrosion-resistant stainless steel alloys release significant extractables under the test conditions. These results are supported by the trend that the main metal ions extracted correlate with the metals composition of each alloy. The iron-based alloys (316L and AL6XN) show iron as the highest concentration extractable ion. The nickel-based alloys (I625 and C276) show nickel as their primary extractable.

An interesting trend in normalized metal ions is shown in Figure 1. The concentration of the Fe and Ni remain fairly constant, while the Cr extraction seems to be increasing with time for all the alloys, suggesting that the passivation layer for these alloys may inhibit corrosion, but a steady state of ion extraction is still taking place. The loss of chromium from metal alloys, forming a chromium depleted layer, is associated with the corrosion process.

Figure 2 shows the metal ion concentration response to time of extraction for two alloys, AL6XN and C276. This graph shows the C276 alloy has obtained a steady state as indicated by no significant increase or decrease in metal-ion release with respect to time. The AL6XN shows an increase in the rate of release with time of extraction. This may indicate increased corrosion of the metal surface. This observation is supported by the relative critical tempera-

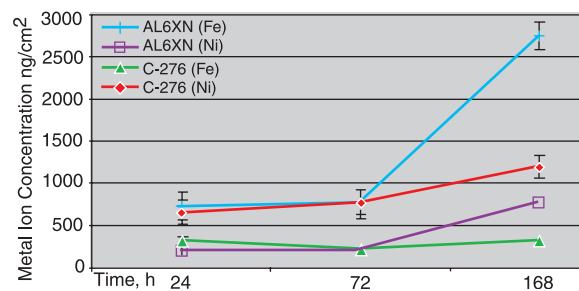


Figure 2. Change in metal ion concentration with time of extraction for AL6XN and C-276 stainless steels.

tures for crevice corrosion for the two alloys.

In Table 3, the total concentration of the primary extractable metal ions is shown along with a projection of daily metals contamination in a 2,000-L vessel, based on the 24-h results. This calculation assumes that the metal is in continuous contact with an environment similar to the test conditions. The environment that the vessel or piping is exposed to is determined by position in the production process. We can assume that it will be subjected to various CIP, media preparation and transport operations that are harsh with respect to chemical and thermal conditions. As indicated by these results, significant contamination exists from even the corrosion-resistant metals which could be eliminated by the use of fully fluorinated fluoropolymers, such as PFA, as a lining or a material of construction in biological applications.

CEP

### Literature Cited

1. Fleming, J. R., et al., "Material of Construction for Pharmaceutical and Biotechnology Processing: Moving into the 21st Century," *Pharmaceutical Engineering*, pp.1-6 (Nov./Dec. 2001).
2. ASTM Standard G48-00, "Standard Test Method for Pitting and Crevice Corrosion Resistance of Stainless Steels and Related Alloys by Use of Ferric Chloride Solution," American Society for Testing Methods, West Conshohocken, PA (May 2000).
3. Metal Samples Co., P.O. Box 8, 152 Metal Samples Rd, Munford, AL 36268.
4. Chemtrace, Inc., 44050 Fremont Blvd., Fremont, CA, 94538.

**LAURI L. JENKINS** has been with DuPont for four years and is currently working in the Fluoropolymer Solutions business in product and applications development to support the pharmaceutical and biopharmaceutical industries (Phone: (302) 999-2404; E-mail: Lauri.L.Jenkins@usa.dupont.com). Jenkins received her Ph.D. in materials science and engineering and a Masters degree in organic polymer chemistry from the University of Florida. She also holds a Masters degree in industrial chemistry from the University of Central Florida.

**SHARON A. LIBERT** has been employed at DuPont for the past 24 years in various manufacturing, sales and technical assignments supporting DuPont's fluoroelastomer and fluoropolymer businesses. She graduated from Auburn University with a B.S. in chemical engineering.

**VICTOR LUSVARDI** is the chief technical officer for Cowie Technology (Phone: (856) 692-2828; E-mail: inquiries@cowie-tech.com). Prior to joining Cowie Technology, he held various technical and business positions within DuPont. Lusvardi earned his B.S. and Ph.D. in chemical engineering from the University of Illinois and University of Delaware, respectively.