

An Annotated Bibliography on Sampling Line Losses

Vytenis Babrauskas, Ph.D.
Fire Science and Technology Inc.
9000 – 300th Place SE, Issaquah WA 98027

Abstract

To conduct real-time analysis of gases produced in a fire experiment requires that they either be analyzed *in situ*, or else conveyed by means of tubing to an analytical apparatus (e.g., FTIR). If the latter option is used, there is potential for serious errors in reporting, if significant losses occur onto the walls of the tubing. This is especially a problem with acid gases, e.g., HCl, HF, HBr. A similar problem exists in air pollution studies, where many species (e.g., ozone) are also easily lost onto surfaces. The following Bibliography was compiled to develop a recommendation for the best sampling-line material to use. It is evident from the studies examined that no one material can be deemed to be “nearly loss-free” under all conditions and for all chemical species needing to be analyzed. On a practical basis, high-purity, synthetic fused silica is found to have the least problems with line losses. Due to its brittle nature, it may not be suitable for all applications. The second-best material was found to be Teflon PTFE, which is suitably flexible. Either type of line should be heated to approximately 150°C to avoid condensation losses.

Bibliography

Ainsworth, J.E., Hagemeyer, J.R., and Reed, E.I., Error in Dasibi Flight Measurements of Atmospheric Ozone due to Instrument Wall Loss, *Geophys. Res. Letters* **8**, 1071-1074 (1981).

Measured ozone losses to PTFE tubing as a function of flow rate; found that losses increased as soon as flow became turbulent; otherwise, followed laminar theory of Levich.

Altshuller, A.P., and Wartburg, A.F., The Interaction of Ozone with Plastic and Metallic Materials in a Dynamic Flow System, *Intl. J. Air and Water Pollution* **4**, 70-8 (1961).

Ozone adsorption was tested at room temperature and no moisture, with flow rates in the range of 0.2 to 2.0 L/min. Type 304 stainless steel and aluminum tubings were very lossy, and required several hours before adsorption became <100%. With enough conditioning, steady state losses dropped to <15%. Polyethylene and PVC (Tygon and Nalgon) tubing were much more lossy, both in transient and in ultimate conditions. Glass lines required a short preconditioning only. No adsorption losses were found with Teflon.

Appel, B.R., and Toriwa, Y., Atmospheric Particulate Nitrate Sampling Errors due to Reactions with Particulate and Gaseous Strong Acids, *Atmos. Environ.* **15**, 1087-9 (1981).

Documents how reactions may take place on a filter between a solid particulate (ammonium nitrate) and a gas (hydrogen chloride) to change the gaseous product (into HNO₃).

Appel, B.R., Wall, S.M., Tokiwa, Y., and Haik, M., Interference Effects in Sampling Particulate Nitrate in Ambient Air, *Atmos. Environ.* **13**, 319-325 (1979).

Studied flows of NO₂ and nitric acid past various filters. Found that Teflon was satisfactory, but that cellulose, cellulose acetate, and glass fiber filters were not since reactions occurred on the filter. There was no correlation between filter pH and performance.

Arnold, J.E., and Fales, H.M., A Comparison of Column and Connector Materials in the Gas Chromatography of Sensitive, High Molecular Weight Compounds, *J. Gas Chromatography* **3**, 131-3 (1965).

Teflon GC columns cause significant tailing, compared to glass; stainless steel and aluminum are not quite as good as glass but better than Teflon; copper is unusable because of numerous reactions.

Baker, R.A., and Doerr, R.C., Methods of Sampling and Storage of Air Containing Vapors and Gases, *Intl. J. Air Pollution* **2**, 142-158 (1959).

In these tests all runs were at ambient temperature, but humidity was varied, although not quantified. Mylar (polyester), which could hold well NO₂ for long times dry, became quite lossy at higher RH. Saran and Scotch-pak (polyester) were somewhat better. SO₂ showed similar rankings. A number of hydrocarbons tested showed little loss under test conditions. Glass flasks (under unspecified moisture) showed substantial storage losses with SO₂ and NO₂, and small losses with pentene. Stainless steel tanks showed no loss for those three gases.

Barratt, R.S., The Preparation of Standard Gas Mixtures, a Review, *The Analyst* **106**, 817-849 (1981). Easy to lose SO₂ and NO₂ on [unspecified type] glass surfaces at ambient pressure and temperature. Conversion on NO to NO₂ problems worse at elevated pressures. NO concentrations over 50 ppm much more stable than ones under 20 ppm. Silanizing steel walls may be useful for NO.

Beck, S.M., and Kell, K.S., Hydrazine Sampling Line Tests, unpublished report, Aerospace Corp. (1986). Studied losses from a 1 ppm hydrazine supply (in nitrogen, at room temperature), over a 100 ft. tubing length. Two levels of humidity were used, 0 and 80% R.H. Seven materials were tested. In all cases, some "conditioning" of the walls was required before steady state readings were reached; in no case was better than 85% recovery in steady state obtained, but some specimens were substantially worse than that. The rank ordering, best to worst, was: Teflon PTFE, high density polyethylene, polypropylene, Teflon FEP (better performance from specimens supplied by Zeus than by Plastic Center), Polyflo (this is Kodak's brand of polyethylene, and it showed extreme variability), Teflon PFA.

Brorström-Lunden, E., and Lindskog, A., Degradation of Polycyclic Aromatic Hydrocarbons during Simulated Stack Gas Sampling, *Environ Sci. Tech.* **19**, 313-316 (1985). Sketchy work on loss of PAHs when exposed to various combinations of acid gases, including SO₂, SO₃, NO, NO₂, and HCl. The temperature was apparently 150°C, while humidity was unspecified. Most acid gas combinations (no pure gases were studied) suffered significant losses.

Byers, R.L., and Davis, J.W., Sulfur Dioxide Adsorption and Desorption on Various Filter Media, *J. Air Pollution Control Assn.* **20**, 236-8 (1970). Evaluated filter media at room temperature with RH= 10% and 50%. Flow rate was 0.15 L/min of 0.05 and 0.1 ppm SO₂. Membrane filters were satisfactory, but glass fiber ones were not. Filter holders evaluated were made of Tenite (best), Teflon PTFE (almost as good), stainless steel (fair), and aluminum (poor).

Clemons, C.A., and Altshuller, A.P., Plastic Containers for Sampling and Storage of Atmospheric Hydrocarbons Prior to Gas Chromatographic Analysis, *J. Air Pollution Control Assn.* **14**, 407-408 (1964). Studied the decay of simple hydrocarbon gases stored in Mylar bags over 10 day periods. Paraffinic gases showed no losses; however, acetylene and ethylene showed 10 to 20% decay over the 10 day period. Only ambient storage temperature was used; humidity was not controlled.

Confer, R.G., and Brief, R.S., Mylar Bags Used to Collect Air Samples in the Field for Laboratory Analysis, *Air Engineering* **7**, 34-6 (October 1965). Mylar sampling bags, of 10 liter capacity and unspecified thickness, were tested for decay of stored gases, primarily solvents. Test periods ranged from 96 to 288 hours. Stored gas concentrations were in the range of 100 to 200 ppm. Samples were not conditioned to a specific humidity level, and were at room temperature. SO₂ concentrations dropped to 15% of the original level after a week of storage, presumably

due to the high concentration of water vapor. Oxygen migrated into bags which originally had sub-ambient oxygen levels; this effect was pronounced. After 120 hours, typically, the concentrations of solvents had decayed to 70%; if the bag had been conditioned to the gas previously, however, the decay was only to the 85% level. Methyl alcohol was the least-retained of the solvents, dropping to 45% after 120 hours (unconditioned).

Conner, W.D., and Nader, J.S., Air Sampling with Plastic Bags, *Amer. Ind. Hyg. Assn. J.* **25**, 291-7 (1964).

Looked at differences between Mylar and Teflon bags, used to collect SO₂, NO_x, hydrocarbons, and ozone. Found that with most specimens and gases there was a beneficial, but short-lived, conditioning effect. Mylar bags were generally better than Teflon, but it is not clear if that is because of lower sorption or lower porosity. Increasing moisture from none to 60 - 70% RH caused almost no effect in all cases, except for hydrocarbons, where data were not obtained.

Coutant, R.W., Effect of Environmental Variables on Collection of Atmospheric Sulfate, *Env. Sci. and Tech.* **11**, 873-8 (1977).

Found that SO₂ sorption onto filters was minimized if the filter's pH was either neutral or acidic; most filters were alkaline and showed substantial sorption. Acceptable filters were Teflon PTFE (neutral), and cellulose acetate and polyimide (acid).

Dandeneau, R.D., and Zerenner, E.H., An Investigation of Glasses for Capillary Chromatography, *J. High Resolution Chromatography & Chromatography Communications* **2**, 351-6 (1979).

Investigated materials most suitable to capillary GC column use, from the point of view of least reactivity and least active adsorption sites. Found that best results from pure fused silica, with as few as possible metallic impurities. Of the remaining glasses investigated—soda lime, Pyrex, potash soda lead, and uranium types—the variations in performance depended on the class of compound being studied.

Grob, K., Comments to the article "Comparison of methods for the deactivation of glass open tubular columns with PEG 20M," *J. Chromatography* **168**, 563 (1979).

Reports the isolated result that at 250°C when PTFE connections are used in a gas chromatograph, that permeation of room oxygen into the carrier gas stream occurs, through the PTFE material.

Groth, R.H., and Doyle, T.B., Some Practical Aspects of Quantitative Gas Chromatography for Determining Low Concentrations of Contaminants, *J. Gas Chromatog.* **6**, 138-143 (1968).

Studied low concentrations (3-20 ppm) of CO₂, under dry conditions. Found that copper and aluminum sampling lines caused substantial adsorption losses, unless travel times were fast; whereas stainless steel lines did not cause losses. Found that these low concentrations were also unstable in stainless steel bottles, but did not explore alternative bottle materials.

Haack, L.P., LaCourse, D.L., and Korniski, T.J., Comparison of Fourier Transform Infrared Spectrometry and 2,4-Dinitrophenylhydrazine Impinger Techniques for the Measurement of Formaldehyde in Vehicle Exhaust, *Anal. Chem.* **58**, 68-72 (1986).

Studied the losses of formaldehyde from a combustion gas source. Using an unheated 45.7 m Teflon line, 9.5 mm I.D., preceded by a 142 mm quartz fiber (Pallflex 2500QA) filter held at 55°C. The humidity was not specifically identified, but included engine exhaust diluted by about 10:1. Formaldehyde concentrations of 0.02 to 8 ppm were tested. Typically, 95% of the formaldehyde was successfully transferred through filter and sampling line; however, it was not reported how long it took to achieve a steady-state delivery.

Jacobson, J.S., and Heller, L.I., Evaluation of Probes Used for Source Sampling of Hydrogen Fluoride, *J. Air Pollution Control Assn.* **26**, 1065-1068 (1976).

Ran tests and 25 and 70°C, and at three RH values, using five concentrations of HF. Teflon showed no losses. An aluminum line coated with methyl methacrylate showed a poor performance. Pyrex and stainless steel were satisfactory for steady state monitoring, but not for transients.

Kang, Y., and Wightman, J.P., Adsorption of Hydrogen Chloride on Microcrystalline Silica (CR-158018), NASA (1979).

Provides adsorption and desorption isotherms for HCl on pure silica and on some NASA sand particles from a launch site.

Lee, W.G., and Paine, J.A., Stability of Nitric Oxide Calibration Gas Mixtures in Compressed Gas Cylinders, pp. 210-9 in *Calibration in Air Monitoring*, ASTM STP 598, ASTM (1976).

NO is quite stable in inert, dry mixtures in type 304 stainless steel cylinders, and even slightly better if cylinder has been SiH₃ treated.

Lusis, M.A., The Effect of Sample Humidity on the Response Characteristics of SO₂ and NO_x Analyzer Systems: Aircraft Plume Dispersal Studies, *J. Air Pollution Control Assn.* **28**, 26-29 (1978).

Studied losses of very low concentrations (<2 ppm) of SO₂ and NO_x on a 6.3 m long polyethylene line and a 1.3 m long PTFE line, under ambient temperature, with 30% and 90% RH. For flow rates of 0.2 to 2.5 L/min, response time constants of about 5 s were noted. Plateaus were much more delayed with the higher RH; PTFE was better than polyethylene for both gases; SO₂ was more moisture sensitive and easier to lose than NO_x.

MacLeod, W.D., Jr., and Nagy, B., Deactivation of Polar Chemisorption in a Fritted-glass Molecular Separator Interfacing a Gas Chromatograph with a Mass Spectrometer, *Anal. Chem.* **40**, 841-2 (1968).

Found that on a glass separator, at 150-200°C, was losing alcohols, aldehydes, esters, and ketones from stream. Silanization with dimethyl-dichlorosilane did not achieve a reduction in the loss of polar organic compounds. However, when silanized with bistrimethylsilylacetamide (BSA), performance was increased greatly for all these organics. Treatment involved applying a small amount of BSA to the glass surface, which was at 150°C and under a vacuum, letting sit for 30 mins., then baking out and pumping down.

Malte, P.C., and Kramlich, J.C., Further Observations of the Effect of Sample Probes on Pollutant Gases Drawn from Flame Zones, *Comb. Sci. Tech.* **22**, 263-269 (1980).

Discusses CO and NO_x loss problems in flame zones; recommends reduced pressure sampling. Results probably not applicable to sampling away from the flame zone.

Maltenieks, O.J., Transparent rain-repellent polymer coatings, *Modern Plastics* **48**:2, 68-72 (Feb. 1971).

Brief summary of properties of hydrophobic polymers of the class of silazanes and siloxanes, along with a bibliography; no actual adsorption data. The durability, especially of the siloxane coatings, is not very great under a simulated rainstorm test.

Marckmann, J., Untersuchungen des Wandhaftungseffektes von Fluorwasserstoff hinsichtlich der Beeinflussung der Messgenauigkeit bei Konzentrationsmessungen, Bericht [unpublished report]. Bodenseewerk Gerätetechnik GmbH, Ueberlingen, Germany (1980).

Despite title, this report is on the adsorption losses of HCl, not HF. Used 180°C atmospheres, with 200 g/m³ H₂O and 4 g/m³ HCl, exposed specimens for 2 hours; rinsed off with nitrogen for 15 min.; then measured time and quantity desorbed of Cl⁻ with steam. Results: Teflon best (although still non-negligible Cl⁻ pickup); aluminum with hard-coat anodizing, about 6 times more adsorption; type 1,4310 steel, about twice again as bad; type 1,4541 steel, about 3 times worse yet; steel with proprietary coating, coating disappeared. Is planning to do work with electropolished type 1,4541 steel, steel 1,4571, and a coated aluminum; also work with HF.

Notoya, T., and Poling, G.W., Benzotriazole and Tolyltriazole as Corrosion Inhibitors for Copper and Brasses, *Boshoku Gijutsu* **30**, 381-9 (1981).

Found that the combination of these two agents more effective than either one alone and suggest that BTA is a film-forming inhibitor, while TTA is an adsorptive inhibitor.

Okamoto, H., and Tuzi, Y., Adsorption of Water Vapour on Glass and Other Materials in Vacuum, *J. Phys. Soc. of Japan* **13**, 649-655 (1958).

Studied adsorption of water at vacuum conditions and up to 130°C on borosilicate and soda-lime glasses, Al₂O₃, OFHC copper, and nickel. Found that the time constant (to full surface layer coverage) decreased at higher temperatures, and that the amount adsorbed, least to most, was: copper, borosilicate glass, nickel, soda-lime glass, Al₂O₃. At the low pressures used there was less than 1% of a monomolecular layer, thus results may not apply to ambient conditions.

Pelizzari, E.D., et al., Evaluation of Sampling Methods for Gaseous Atmospheric Samples (Report on Contract 68-02-2991, prepared for Environmental Sciences Research Laboratory, Environmental Protection Agency, Research Triangle Park, NC). Research Triangle Institute, Research Triangle Park, NC [ca. 1983].

Ran tests on various candidate materials used for making air sampling containers; also tested traps (will not summarize these tests). Tested Tedlar, Teflon FEP sample bags, and also electropolished stainless steel (304) cans and Pyrex glass bulbs for stability of low-level mixtures, containing typically 50 ppb of aromatics and chlorinated organics. Tests were run at RH= 30% and 90%, and included, in some cases, ppb levels of O₃, SO₂, and NO_x added as potential interferents. For the bags, recovery was typically higher for Tedlar than for Teflon FEP. Nitrobenzene showed an especially low recovery. For the metal cans and glass bulbs, recovery was generally worse for higher boiling point compounds. Benzyl chloride seemed especially easily lost in the glass and steel containers. For electropolished steel, it was found that recovery was better from can commercially prepared by a proprietary process, than ones prepared in the lab. Found that cleaning Teflon FEP bags after using with heavier molecular weight aromatic hydrocarbons was difficult to do by air-flushing alone, and the ozonation and irradiation were necessary to fully desorb the test compounds. This problem did not arise with the Tedlar bags. Tedlar bags, however, showed some problem of offgassing solvents carried over from their original manufacture. Both Teflon FEP and Tedlar bags also exhibited losses due to permeation out through the plastic. When inorganic interferents were added, the recovery diminished most significantly for the electropolished steel cans. However, taken over the entire range of 27 tested compounds, the commercially electropolished 304 stainless cans showed the highest recovery.

Pelizzari, E.D., private communication.

In studying a gold-coated silica transfer line, found that losses of some unidentified compounds were occurring. Studied a 3-ft long nickel line, at 100°C, found that tertiary butynol was dehydrating; problem became much less serious for an 18" line. Even going to very high temperatures (325°C) was not enough to stop condensation of high MW hydrocarbons and PAHs. Would expect very poor results from Teflon due to high permeability. Prefers silica tubing which is deactivated and coated with a GC stationary phase.

Pike, R.G., and Hubbard, D., Physicochemical Studies of the Destructive Alkali-Aggregate Reaction on Concrete, *J. Res. NBS* **59**, 127-131 (1957).

Studied adsorption of H₂O onto different glasses. At room temperature, the ranking, most sorptive to least sorptive, was: soda-flint, Pyrex (borosilicate), fiber-glass, fused silica.

Rose, S.L., Lapallo, A., and Hawkins, C.M., Material Compatibility with Threshold Limit Value Levels of Monomethylhydrazine, Naval Research Labs., Letter report 9510/6110-13a (1985).

Studied the performance of ppb level flows of MMH in air streams at 8, 21, and 40°C and 20, 45, and 65% RH. Line lengths were 8 to 75 ft, with I.D. range of 1/8" to 1/4". TFE and FEP Teflons performed best, followed by high-density polyethylene and polypropylene. Copper lines were completely unacceptable, while steel was only slightly better. Tygon performed most poorly among plastics. Also tested were acrylic, nylon, polycarbonate, and Tenite and Bev-a-Line plastics.

Samuelsen, G.S., and Harman, J.N., III, Chemical Transformations of Nitrogen Oxides While Sampling Combustion Products, *J. Air Pollution Control Assn.* **27**, 648-655 (1977).

Studied NO_x transformations and removals in Vycor silica and 316 stainless tubing, with and without CO and H₂, but always with CO₂ and O₂. A flow rate of 4 L/min in a 2 m long tube were used. For both tubes, up to 100 °C, no losses were noted. At higher temperatures, adding CO caused greater losses. Effects of hydrogen were complicated. Silica was always better than stainless. No H₂O was used.

Schuette, F.J., Plastic Bags for Collection of Gas Samples, *Atmos. Environ.* **1**, 515-9 (1967).

Briefly annotated bibliography of plastic bags (Mylar, Saran, Teflon, Scotch-pak, and Kel-F) for gas handling. It does not appear that any of the tests reported involved elevated temperatures or moisture.

Sindorf, D.W., and Maciel, G.E., Solid-State NMR Studies of the Reactions of Silica Surfaces with Polyfunctional Chloromethylsilanes and Ethoxymethylsilanes, *J. Amer. Chem. Soc.* **105**, 3767-3776 (1983).

Details of what happens at a silanized surface.

Spicer, C.W., Holdren, M.W., Lyon, F.F., and Riggin, R.M., Composition and Photochemical Reactivity of Turbine Engine Exhaust (ESL-TR-84-61). Air Force Engineering and Services Center (1984).

Is studying total hydrocarbons, NO_x, and CO in combustion gas streams. Has found satisfactory a sampling arrangement consisting of a 100 ft line of 1/2 inch Teflon, heated to 150°C.

Spicer, C.W., and Schumacher, P.M., Particulate Nitrate: Laboratory and Field Studies of Major Sampling Interferences, *Atmos. Environ.* **13**, 543-552 (1979).

Studied various nitrogen-containing gases flowing past a number of filters to determine potential for erroneous measurements due to interactions between the gas and a layer of either carbon black or collected pollutant particulate deposited on the filter. Found that Teflon and polycarbonate filters did not show any errors; errors were low with one brand of proto-type quartz filter. With other quartz filters, and also with cellulose acetate and glass fiber filters the artifact nitrate collection was significant. The worst performer was nylon. Filters tended to saturate when a limit value of artifact nitrate was collected, and further nitrate was then not scrubbed out.

Wechter, S.G., Preparation of Stable Pollution Gas Standards Using Treated Aluminum Cylinders, pp. 40-54 in *Calibration in Air Monitoring*, ASTM STP 598, ASTM (1976).

Low ppm mixtures of CO tend to suffer losses in steel cylinders; same is true of SO₂, even when in stainless steel cylinders. Better results are obtained with aluminum cylinders, where an aluminum oxide surface is over-coated with a proprietary Airco, Inc. coating.

Westendorf, R. G., A Critical Examination of Tubing Materials Used in Concentrator Systems, Paper 1078 presented at The Pittsburgh Conference & Exposition on Analytical Chemistry and Applied Spectroscopy, Atlantic City (1987).

Experimental rig consisted of 1 m long sections of 0.5 mm I.D. test tubing, heated from 25 to 350°C, then fed into a capillary GC, using a Tekmar cryofocusing attachment at the GC, in order to make up for having a large-diameter tubing ahead of it. The GC injection port was removed from the GC and placed in front of the test tubing. The injection port and the test tubing were both heated to the same temperature. Carrier flow rate was 10 mL/min of H₂. The detector was a standard FID. To maximize the effect of

sample losses, the amount injected was small (1 ng); this was as small an amount as could be used and still find a suitable standard. The test tubings included stainless steel, nickel, nickel coated with an 0.05 μm layer of elemental silicon, fused silica, and steel tubing with a glass lining. The last material was not yet started. The metal tubings were solvent-rinsed and acid-washed prior to use. The silica tubings were used as-is (however, if difunctional amines are concerned, some surface treatment may be necessary). The species to be tested were the 229 Priority Pollutants on the EPA list. Analysis was done by (1) looking at the area under the GC peak, and comparing that to what is available for other temperatures or tubings; and (2) checking that a reaction/decomposition product had not been formed. Reproducibility of peak heights was typically ca. 2% in cases where no losses occurred, up to about 5 to 20% in the lossy cases. No experiments were done with any conditions other than fully-dry carrier, and carrier flow rates were also not varied. Did not include Teflon tubing in series, even though it is quite unreactive, since knows of tailing problem. For dichlorobenzene, with the SS tubing results were fine up to 125°C. At 150°C, some decomposition products were being formed. By 225°C behavior was quite poor. For 1,1,2,2-tetrachloroethane, with SS tubing there were serious losses both at low temperatures and at high ones. For nickel, losses started appearing for >200°C. The Si-coated nickel showed losses for < 80°C. The fused silica showed losses for < 50°C. It was noted that the decomposition mechanism was dehydrohalogenation. For 1,2-dichloroethane and dichloromethane, SS and nickel tubings started showing losses for > 240°C. For chloroform and 1,1,1-trichloroethane, SS and nickel tubing started showing losses for > 200°C. For 1,2,4-trichlorobenzene, nickel showed losses for > 200°C. SS showed losses for < 70°C, due to physical adsorption, and then for > 200°C. For 2-chloroethylvinyl ether, nickel and SS both showed decompositions for > 120°C. For acrylonitrile, nickel was poor for > 160°C, but SS showed losses for <150°C. For bromoform, SS showed losses for < 100°C. In general, concludes that 135°C is the best operating temperature, and fused silica is the best material tested. If any salts are present, however, catalysis and breakdown occurs on all surfaces, including fused silica; however, at least this one is easy to clean out and restore to service.

White, A., and Beddows, L.M., The Choice of Sampling Tube Material in the Determination of Nitrogen Oxide Concentrations in Products of Combustion, *J. Appl. Chem. and Biotechnol.* **23**, 759-767 (1973). Studied loss of NO_2 (25 ppm concentration) from dry bottled gas at various temperatures. Flow of 1.2 L/min down a 2 m line. Found that stainless steel lines got totally lossy at about 250°C; for mild steel and copper, the temperature was 200°C. Also examined plastic tubes at room temperature; found PTFE satisfactory, but nylon, ethyl vinyl acetate (EVA), and PVC never equilibrated. PTFE still had good performance at its maximum service temperature of 200°C.

Wilson, K.W., and Buchberg, H., Evaluation of Materials for Controlled Air Reaction Chambers, *Ind. and Eng. Chem.* **50**, 1705-8 (1958).

Tested for effects of ozone, NO_2 , acetone, methanol, pentane, and cyclohexene on Kel-F, polyethylene, Saran, PVC films and also aluminum and stainless steel. Metal details were not specified. Only room temperature tests with no moisture were conducted. NO_2 was adsorbed seriously by aluminum, PVC, and glass, and only insignificantly by the other plastics. The organic vapors were tested only with Kel-F, which was satisfactory, and polyethylene which was much too porous. Ozone losses were small with glass, Teflon and Kel-F, and with stainless steel, both plain and silicone coated. Ozone losses were greater for the other materials.

Wohlers, H.C., et al., Sulfur Dioxide Adsorption on—and Desorption from Teflon, Tygon, Glass, Stainless Steel and Aluminium Tubings, *Atmos. Environ.* **1**, 121-130 (1967).
[see combined results under the following reference]

Wohlers, H.C., Newstein, H., and Daunis, D., Carbon Monoxide and Sulfur Dioxide Adsorption on—and Desorption from Glass, Plastic, and Metal Tubings, *J. Air Pollution Control Assn.* **17**, 753-6 (1967).

Air flow rate (1.4 to 105 L/min), tubing length, diameter, and RH (17 to 90%) were varied in these tests, although raw data are not reported. Teflon, polypropylene, glass and stainless steel showed no significant losses at RH up to 68%. One test with stainless steel at 90% RH showed that 100% of the SO₂ was being lost. Aluminum PVC performance was less good than the other materials. None of the materials showed any problems in transporting CO.

Copyright © 2003 by Vytenis Babrauskas