How Weld Hose Materials Affect Shielding Gas Quality

BY PAUL M. BHADHA

Every component of a gas delivery system can contribute contaminants

Many defects in welds made with gas tungsten arc welding (GTAW), gas metal arc welding (GMAW) and plasma arc welding (PAW) processes can be traced to contaminants such as oxygen and moisture in the shielding gas. Often the entire gas delivery system, rather than just the gas cylinder, is the cause. Commonly used materials of construction for weld torch tubing and hoses — such as PVC and other plastics — can significantly degrade shielding gas quality because atmospheric moisture and oxygen can permeate through the hose walls.

Areas of Concern

While determining sources of impurities in gas delivery systems, the major areas of concern include the gas cylinder, piping system, hoses, tubing and other plastic/nonmetallic components.

Gas Cylinders

Occasionally, a gas cylinder runs dry, allowing moist air to back flow into the cylinder, which causes rust formation on the cylinder's inner wall. Acting like a sponge, the rust soaks up air and moisture during subsequent fillings, then releases a portion of these contaminants to the cylinder gas, perhaps continually over the life of the cylinder. Thus, a single accident can result in dirtier gas to all subsequent users of the cylinder.

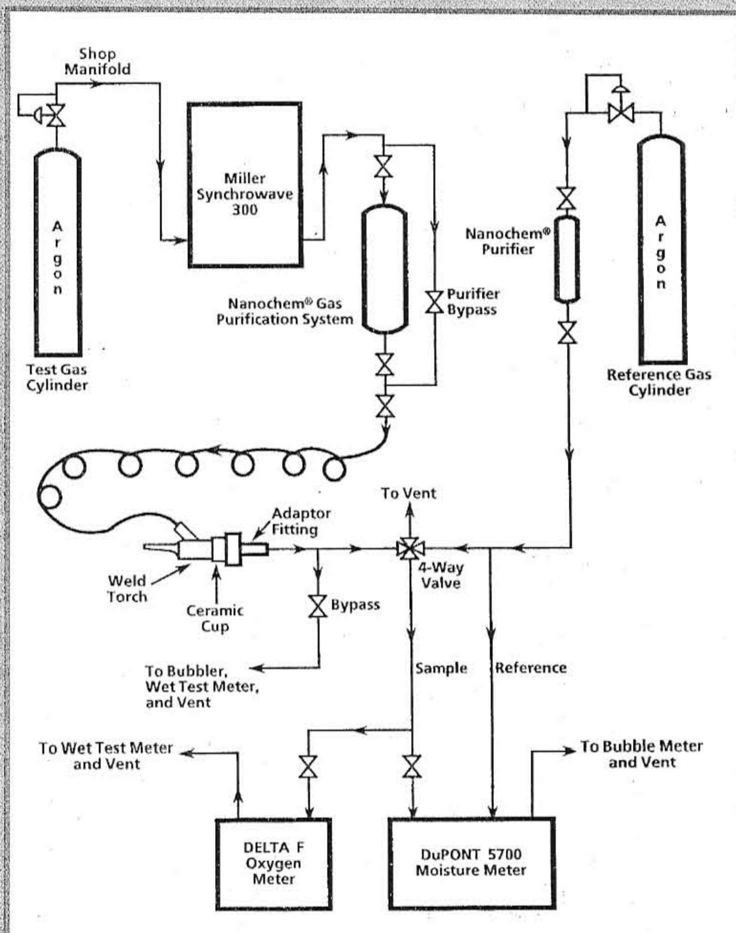

Fig. 1 — Analysis of moisture and oxygen in shield gas at the weld torch.

Gas suppliers conduct a hydrostatic pressure test of their cylinders every five years, also causing rust formation and resulting in moisture contamination.

PAUL BHADHA is a consultant for Matheson Gas Products, Parsippany, N.J., and other corporations.

Highest ←		PERMEATION			→ Lowest
Neoprene Rubber	Butyl Rubber	PVC Tygon	PE (high density) Polypropylene Teflon PTFE	Kel-F Saran	Metal

Fig. 2 — Degrees of permeability.

Table 1 — Impurity Concentration at Weld Torch

	Without Shield Gas Purification[a]		*With* Shield Gas Purification[b]	
Flow Rate ft³/h	Oxygen ppm	Moisture ppm	Oxygen ppm	Moisture ppm
20	0.53	40	0.39	20
40	0.55	22	0.31	11

Room Temperature: 25°C
Gas Cylinder Quality: Oxygen – 0.1 ppm, Moisture – 4 ppm.
(a) Impurities contributed by gas cylinder, piping manifold and 30-ft PVC tubing to weld torch.
(b) Impurities contributed by 30-ft PVC tubing alone (from permeation of atmospheric oxygen and moisture).

Most GTAW users specify argon gas with 99.995% purity, and occasionally even 99.998% purity (obtained by pre-purging gas cylinders prior to filling). Note that a 99.995%-grade gas can still contain up to 50 parts per million (ppm) of total impurities, and 99.998% up to 20 ppm. In many critical welding applications, such levels may be high enough to cause defects or premature corrosion. An off-spec or dirty cylinder could contain much higher levels of impurities.

Piping Systems

Many large fabricators and repair shops use a centralized supply of liquid argon. While argon from this tank is very pure (less than 2–5 ppm total impurities), such low levels are usually attainable only at the immediate outlet of the tank. The gas then travels through a piping network (manifold system) anywhere from several hundred feet to a few miles long, and just about every component in that network can be a source of leaks. Impurities trapped in piping joints, such as Ts, where there is not continuous flow, may continue to desorb into the rest of the piping manifold for days or even months. In most cases, the quality of the gas at the weld torch is significantly poorer than at the liquid bulk supply.

Plastic and Nonmetallic Components

Hoses and plastic tubing are commonly used to obtain flexible joints, such as when connecting a gas cylinder to a power source or to deliver gas from the power source to the weld torch. Such nonmetallic joints can significantly degrade gas quality. Atmospheric moisture and oxygen — at the molecular level — can diffuse through the solid walls of plastic parts and thereby contaminate the gas stream flowing within the plastic tubing or component (such as valve seats, O-rings, etc.). Called atmospheric permeation, the resulting contamination may be aggravated by leakage through poorly crimped hose connections and loose or damaged fittings, resulting in a much higher level of contaminants at the weld torch.

Purification

To determine the precise effects of atmospheric permeation, tests and test welds described were performed at a weld shop in the Research Center of Hercules Inc., Wilmington, Del. Relatively clean argon gas containing only 0.1 ppm oxygen and 4 ppm moisture was allowed to flow at 20 ft³/h (6 m³/h) through the weld shop manifold, a Miller Synchrowave 300 power source and a Linde HW-18 weld torch. The shop manifold consisted of about 75 ft (22.5 m) of ½–1 in. (12.7–25.4 mm) inside diameter carbon steel piping.

Typical of such manifold installations, the quality of argon at the outlet of the weld torch had deteriorated to 0.5 ppm oxygen and 40 ppm moisture. In passing through the manifold, piping, power supply unit, connecting hoses and the weld torch, the moisture content of the gas had increased tenfold — from 4 to 40 ppm.

A NANOCHEM® resin-based gas purifier was installed at the outlet of the welding power source (Fig. 1), and the moisture concentration at the weld torch was immediately reduced to 20 ppm. Since the moisture concentration was measured to be less than 0.05 ppm at the immediate outlet of the gas purifier and no leaks were found in the tubing and other components, permeation of atmospheric moisture through the PVC hose to the torch was suspected.

Atmospheric permeation was confirmed by increasing the gas flow rate while keeping the operating pressure constant. Because the amount of permeating impurities stays constant regardless of gas flow rate, a higher flow rate diluted the permeating contaminants in the gas. When the flow rate was doubled from 20 to 40 ft³/h (12 m³/h), the permeate (moisture) concentration was roughly halved (Table 1).

Permeability Factors

All gases, such as oxygen, moisture, carbon dioxide and nitrogen, can diffuse through the walls of just about all rubber and plastic hoses, tubing and other components. Permeation is absent only in all-metal all-welded pipes. If the piping manifold is not welded, permeation can occur at pipe-thread connections, which are usually sealed with a plastic, such as Teflon tape. Table 2 lists permeability coefficients for several known plastics that might be used in gas delivery systems (Ref. 2–7). SI units of permeability have been used. The higher the permeation coefficient, the higher the amounts of the diffusing contaminant and the worse the quality of the ensuing gas. For critical gas purity requirements in welding, a permeation coefficient less than 100 can be considered acceptable; permeation coefficient below 10 would be excellent.

Rubber hoses are often used in welding applications because of their strength and flexibility, but most have high permeation

Table 2 - Permeability Coefficient of Common Polymers (Plastics)

Polymer	Common/Trade Name	Permeability Coeffcients at 25∞C (P × 10^{10}) Oxygen	Moisture
Poly(isoprene)	Natural Rubber	23.3	2290
Poly(chloroprene)	Neoprene G	4.0	910
Poly(isobutene-coisonrene)	Butyl Rubber	1.3	110
Poly(vinyl chloride)	PVC (unplasticized)	0.045	275
Poly(tetrafluoroethylene)	Teflon	4.2	4.8
Poly(tetrafluoroethylene-co)	Teflone FEP	4.9	17
Poly(ethylene), low density (0.914 g/cm^3)	LDPE	2.2	68
Poly(ethylene), high density (0.964 g/cm^3)	HDPE	0.3	9
Poly(propylene) density (0.907 g/cm^3)	PP	1.2	35
Poly(vinyledene chloride)	Saran	0.005	0.5
Poly(trifluoro chloroethylene)	Kel-F81	0.04	0.1
Poly(ethyl methacrylate)	Plexiglas	1.2	3200
Poly(carbonate)	Lexan	1.4	1400
Poly(ethylene terephthalate)	PET	0.035	130

Permeability Coefficient P = (amount of permeate) (film thickness)/(surface area) (time) (pressure-drop across film).
Units of P: [cm^3 cm]/[cm^2 s (cm Hg)].

Table 3 — Effect of Polymer Density/Crystallinity on Permeation

Polymer	Density g/cm^3	Crystallinity %	Permeation Constant P at 30°C (P ×10^{10}) Oxygen	Nitrogen	Carbon Dioxide
Polyethylene	0.922	60	5.5	1.9	25.2
	0.938	69	2.1	0.66	7.4
	0.954	78	1.1	0.33	4.3
	0.96	81	1.06	0.27	3.5
	0.965	83	0.5	—	2.5
Polypropylene	0.907	~50	2.1	0.42	8.4

Peameability Coefficient P = (amount of permeate) (film thickness)/(surface area) (time) (pressure-drop across film).
Units of P: [cm^3 cm]/(cm^2 s (cm Hg)].

coefficients (Table 2). In recent years, PVC tubing has replaced rubber hoses, but even PVC has a fairly high moisture permeability coefficient, at 275. Fluorinated polymers, on the other hand, such as Kel-F 81 and Teflon, have very low oxygen and moisture permeability (Table 2). Indeed, Kel-F 81 has the lowest water vapor permeability of all known plastics (Refs. 3, 7). Unfortunately, Kel-F tubing is only commercially available in very small sizes for medical applications.

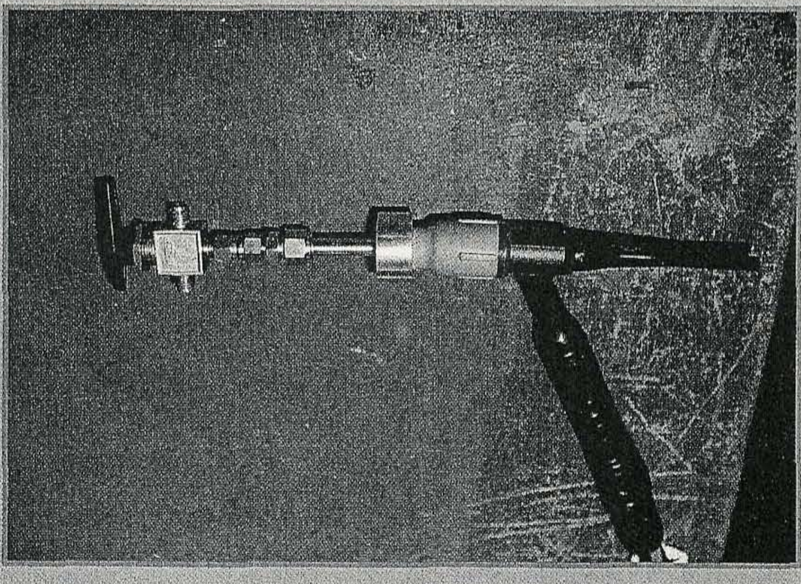

Fig. 3 — Accessory for measuring impurities in shielding gas at weld torch tip.

Permeation Properties

Permeation through plastics is primarily dependent upon the following properties:

1. *Exposed surface area.* The longer the hose or the bigger the hose diameter, the greater the permeation.

2. *Length of diffusion path.* The longer the path for the impurity to diffuse, the less the permeation. Thick-walled hoses allow less permeation.

3. *Material of construction.* The stiffer the hose, the less the permeation — Fig. 2.

4. *Nature of contaminant.* Except for Teflon, most plastics allow a much higher degree of moisture permeation than oxygen permeation.

5. *Humidity.* The higher the humidity of the surroundings, the greater the moisture permeation. Moisture permeation at 90% relative humidity will be double the permeation at 45% relative humidity (at the same room temperature).

6. *Temperature.* The higher the room temperature, the higher the moisture permeation (at the same relative humidity). For example, the moisture permeation rate at 95°F (35°C) is approximately double the rate at 75°F (24°C). Welding on hot, humid days may result in more weld defects.

Table 4 — Driving Forces for Atmospheric Diffusion

Gas Constituent	Concentration of Gases *Inside* Hose ppm A	Concentration of Gases *Outside* Hosse (Air composition) ppm B	Approx. Driving Force for gases to diffuse out of hose to atm ppm A–B	Result
Argon	950,000	9000	941,000	Argon diffuses *out* of hose
Helium	50,000	5	50,000	Helium diffuses *out* of hose
Nitrogen	100	780,000	–779,900	Nitrogen diffuses *in* to hose
Oxygen	20	209,000	–209,000	Oxygen diffuses *in* to hose
Moisture	10	20,300	–20,300	Moisture diffuses *in* to hose

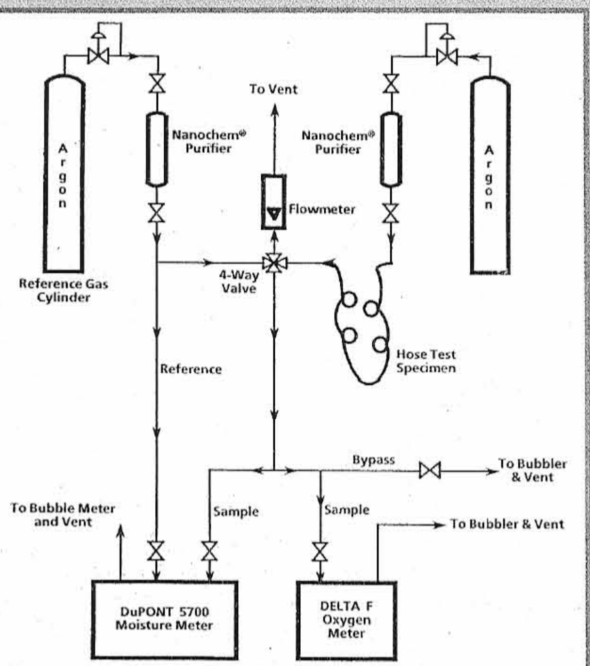

Fig. 4 — Measurement of atmospheric oxygen and moisture permeation through plastic/rubber hoses.

7. *Additives in the polymer.* In general, addition of plasticizers to increase flexibility to the hose (during manufacture) will increase the permeability of the plastic. Addition of inorganic fillers will usually decrease the permeability.

8. *Degree of crystallinity/density of polymer.* Density is a measure of the free volume between the molecules of the polymer. In general, the higher the density, the lower the permeability. The crystalline structure of the polymer is usually less permeable compared to the amorphous form. Crystallinity and density are strongly related. The higher the crystallinity, the higher the density of the polymer. But, more density increases stiffness, giving a less flexible hose. Table 3 shows the effect of crystallinity and density for permeation of oxygen, nitrogen and carbon dioxide through polyethylene and polypropylene (Ref. 8).

Glove Box Applications

Butyl rubber has much less moisture and oxygen permeation than Neoprene rubber (Table 2). So, Butyl rubber gloves should be used for welding applications in a glove box or inert atmosphere chamber and neoprene gloves should be avoided.

Table 5 — Experimental Data, Permeation of Atmospheric Oxygen and Moisture through Weld Hoses

Polymer	Atmospheric Permeation for 8-ft length of hose: Oxygen[a] ppm	Moisture[a] ppm
"Rubber" (Goodyear Conair)	0.77	9.4
PVC (Linde 40V77)	0.12	5.5
Teflon	0.82	0.56

Flow Rate = 20 ft^3/h, Temperature = 20°C (room air-conditioned)
(a) Impurities in test gas and piping manifold removed by gas purification. Indicated impurity levels are due to atmospheric permeation alone.

Glove boxes can be made of Plexiglas and, occasionally, Lexan. Although Plexiglas and Lexan have negligible oxygen permeation (Table 2), the moisture permeation rates are very high. Consequently, glove boxes should preferably be made of metal, with only the windows/viewing ports made of Plexiglas or, preferably, Lexan. Choosing Plexiglas over Lexan would still imply almost 300% more permeation (Table 2). It would be even better to have the windows made of glass, instead of plastic.

Many users measure only the oxygen content of glove boxes, which is often 10 ppm or less. Nevertheless, because of the very high moisture permeation constants of Plexiglas and Lexan (viewing windows), Neoprene and Butyl rubber (gloves and seals), the box's moisture content can be easily 50–250 ppm.

Permeation of Nitrogen — Welding of Titanium

Because of its reactive nature, titanium metal is often welded in glove boxes under an argon atmosphere. One should thoroughly shield the weld with purified shielding and trailing gas, even when welding inside a glove box — with its permeating moisture through its Plexiglas, Lexan and rubber components.

Also, nitrogen in argon can reduce ductility in titanium welds from the formation of titanium nitrides. However, the concentration of nitrogen in argon or helium in gas cylinders is usually small enough that there isn't a major effect on weld quality. The permeation of nitrogen is usually only a quarter the permeation of oxygen in many plastics. Since oxygen permeation is usually too small in most cases, permeation of atmospheric nitrogen into glove boxes is not likely to be high enough to affect weld quality.

Driving Forces for Permeation

Permeation (*i.e.*, diffusion) is a function of the partial pressure of each individual component of the gas mixture, *not* a function of the total pressure of the gas mixture.

Consider a hose carrying a blend of 95% argon/5% helium at 30 lb/in.². Assume the argon/helium blend contains 20 ppm oxygen, 10 ppm moisture and 100 ppm nitrogen. Assume the air outside the hose is at 75°F (23.8°C) at 70% relative humidity. Atmospheric air contains about 78% nitrogen, 20.9% oxygen, 1% argon and 5 ppm helium. At 75°F, the vapor pressure of water is about 22 mm Hg (Ref. 9). Thus, the concentration of moisture in air (outside the hose) is determined to be

$$70\% \times (22 \text{ mm Hg} / 760 \text{ mm Hg}) \times 1{,}000{,}000 \text{ ppm} = 20{,}300 \text{ ppm}.$$

Table 4 shows the driving force (difference in partial pressures) of each individual component of the gas mixture, inside and outside the hose, for the above case. The unmistakable conclusion is that there are large driving forces for permeation of argon and helium from inside the hose to the atmosphere. But large driving forces exist for permeation of oxygen, moisture and nitrogen from the atmosphere into the hose.

Permeation Tests

Table 5 gives results of permeation tests conducted with 8-ft (2.4-m) hose sections of different plastics. These results show that shielding gas quality can be significantly degraded with commonly used materials of construction, such as rubber or PVC. For a standard 30-ft (9-m) weld torch hose, moisture permeation will be almost four times higher than reported in Table 5 — as much as 35 ppm with rubber or 20 ppm with PVC. Note these tests were done in an atmosphere of approximately 50% relative humidity. On hot, humid, summer days, moisture contamination by atmospheric permeation is likely to be higher.

With the Teflon hose, moisture permeation was one-tenth the value for PVC (Table 5). However, the low moisture permeability of Teflon, Kel-F and other plastics is usually at the expense of flexibility. These plastic hoses can be used for connecting gas cylinders or tanks to the delivery manifold, but they are too rigid to be used for a weld torch hose.

A further search revealed that high-density polyethylene (HDPE) and polypropylene (PP) offered sufficient flexibility along with excellent moisture barrier properties. Results indicated that permeation of atmospheric moisture with a PP tubing was less than one-tenth that with a PVC hose. In actual weld tests with a thin-walled polypropylene weld torch tubing, the welder did not experience any significant discomfort or inconvenience.

Pressure Regulators

Inexpensive pressure regulators, common in the welding industry, often use rubber diaphragms instead of the stainless steel ones used on more expensive models. Because of rubber's extremely high moisture permeability, regulators with rubber diaphragms are not recommended for critical welding applications.

The Misguided Popularity of Clear Tygon Tubing

Over the last several years, many users have switched from black PVC tubing to clear Tygon tubing, a tubing perceived to be cleaner. But, Tygon is actually similar to PVC in chemical composition. A few tests were done to evaluate the effectiveness of this clear tubing. Oxygen and moisture permeation results for 8-ft tubes are given in Tables 6–8. The results clearly indicate that the clear Tygon tubing hose is inferior to the black PVC tubing, which has black fillers to reduce permeation. Tables 7 and 8 show the characteristic trend for permeation — a doubling of the flow rate halved the permeate concentration.

The clear Tygon tubing contributed more than 1 ppm moisture for every 1 ft (30.48 cm) of tubing. Indeed, 30 ft of clear Tygon tubing could contribute 35 ppm moisture.

Table 6 — Experimental Results, Comparison of Permeation through Clear Tygon Tubing and Black PVC Tubing

Hose Material	Oxygen Permeation through 8-ft tubing ppm	Moisture Permeation through 8-ft tubing ppm
Clear Tygon	0.7	9
Black PVC Hose	0.1[a]	5.5

Flow Rate= 20 ft³/h, Operating Pressure = ~30 lb/in.²
(a) Value may be slightly higher; a different oxygen meter was used.

Table 7 — Experimental Results, Permeation of Atmospheric Moisture through Clear Tygon Tubing

Relative Humidity %	Flow Rate ft³/h	Moisture Permeation through 8-ft hose length ppm
52	20	9
53	15	13
55	10	18
56	5	34
57	2	95
~35	0.2	465

Operating pressure = ~30 lb/in.²

Table 8 — Experimental Results, Permeation of Atmospheric Moisture through Clear Tygon Tubing

Flow Rate ft³/h	Oxygen Permeation through 8-ft hose length, ppm
20	~0.7
15	~0.9
10	~1.3
5	~2.7

Operating pressure = ~30 lb/in.²

Plasma Welding Applications

In plasma welding applications, a separate gas stream at a very low flow rate, usually 0.5–5 ft³/h (0.15–1.5 m³/h), is sent to the plasma. At such low flow rates, the effects of moisture permeation can be huge (Table 7). Although oxygen permeation is usually not significant at flow rates of 20 ft³/h and higher for most plastics, it can become significant at very low flow rates, such as flow rates to a plasma torch (Table 8).

Test Welds

When impurities in shielding gas are removed with a purifier, and recontamination minimized by using a low-permeability hose, the results can be dramatic. GTA test welds were made with ¼-in. (6.35-mm) beveled aluminum plates at a weld speed of 6–8 in./min (15.24–20.32 cm/mm), at 210–250 A and 24–28 V. Even with a shielding gas containing as much as 200 ppm moisture, weld porosity was completely eliminated when the gas was purified with a resin-based purifier and the gas quality maintained with a polypropylene hose to the weld torch. Welds made with gas purification also showed a significant improvement in ductility, with fewer microcracks, as determined by bending tests.

Experimental Method

Setup

The experimental setup for measuring impurities at the actual point of use (outlet of the weld torch) is shown in Fig. 1. All process lines were made of Type 304 stainless steel with ¼-in. Swagelok compression fittings. A special part, shown in Fig. 3, was fabricated to fit on the ceramic cup of the weld torch. This part enabled testing of the gas at the weld torch. All gas sampling lines were made of flexible stainless steel, Type 316.

Figure 4 shows the permeation test apparatus. Flow rates were calibrated with a wet test meter and a bubble meter. Flow meters commonly used in the welding industry, such as rotameters, can have a flow measurement error of 10–25%. A wet test meter has a maximum measurement error of less than 5%, a bubble meter error of less than 2%. Appropriate correction factors for the vapor pressure of water and the barometric pressure were used to precisely measure the flow rates.

Equipment

A moisture analyzer, Ametek Model 5700 (previously known as the DuPont 5700), was used to measure moisture levels in the sampled gas. This instrument is often used in the semiconductor industry for measuring low levels of moisture; detection limits are about 0.02–0.05 ppm moisture. The unit has a vibrating piezo-electric crystal coated with a hygroscopic polymer. Moisture in the gas is adsorbed on the polymer, changing the mass of the crystal and, thereby, its vibration frequency. The change in the vibration frequency is correlated to the moisture content of the gas (Ref. 10).

Oxygen levels were measured with a Delta F Trace oxygen analyzer; this instrument has a lower detection limit, about 0.05 ppm oxygen. The meter consists of an electrolytic cell containing potassium hydroxide solution. Oxygen in the gas forms electrons in the cell; the generated current is a measure of the oxygen concentration in the gas.

Such oxygen and moisture meters will give accurate readings in the low ppm range only if a very clean gas is used to "zero" the instrument, accomplished here with four-way switching valves and smaller gas purifiers — Figs. 1, 4. A constant purge of purified argon kept the gas sampling lines and the instruments free of moisture and oxygen. Flow from vent lines was sent to oil-filled bubblers to prevent any back diffusion of atmospheric air. Such precautions are necessary; otherwise, the instruments may take a very long time to give accurate readings. Measurement of low ppm levels of moisture in gases is a difficult task because moisture tends to coat on the walls of the tubing, slowly desorbing over time (Ref 10). Such a coating may take hours, even days of purging for complete removal.

Conclusions

Permeation of atmospheric moisture and oxygen in rubber or plastic hoses/tubing can significantly degrade gas quality. At a flow rate of 20 ft^3/h, a 30-ft rubber hose or clear Tygon tubing can easily add 35 ppm moisture to the shielding gas, and a 30-ft PVC hose can easily add 20 ppm moisture.

If a purifier cannot be installed at the weld torch, use a gas purifier at the immediate outlet of the power source. This will provide insurance against shield gas contamination from the entire delivery system upstream of the purifier.

To minimize recontamination of the purified gas by atmospheric oxygen and moisture permeation through the weld torch hose, keep hose and tubing lengths as short as possible. If a welder is working with small parts, a tubing length of 10–15 ft (3–4.5 m) to the weld torch, rather than 30 ft, should be considered. Better still, replace materials such as rubber or PVC with plastics, such as polypropylene or polyethylene, having good resistance to moisture permeation. High density polyethylene or polypropylene tubing is strongly recommended for very low flow rate applications, such as flow to the plasma in plasma welding applications.

Butyl rubber gloves are recommended when welding is done inside a glove box or inert atmosphere chamber. Glove boxes should be built of metal with Plexiglas or Lexan windows/viewing ports. Glass and Lexan are preferable over Plexiglas.

Pressure regulators with stainless steel diaphragms are recommended; regulators with rubber diaphragms should be avoided.

Most importantly, take care while designing a gas delivery system. All its components can contribute contaminants, resulting in a significant reduction in gas quality at the final point of use — the welding torch. ◈

Acknowledgement

The author deeply appreciates the contribution of Kenneth F. Krysiak, principal engineer, Hercules Inc., for his help in the preparation and testing of aluminum welds.

Trademarks

Kel-F is a trademark of 3M Corp.
Lexan is a trademark of General Electric
NANOCHEM.is a trademark of Matheson Gas Products
Swagelok is a trademark of Swagelok Co.
Teflon is a trademark of E.I. DuPont de Nemours & Co., Inc.

References

1. Hardwick, S. J., Lorenz, R., and Weber, D. 1988. Insuring gas quality at the point-of-use. *Solid State Technology* 31(10): 93–95.
2. Brandrup J., and Immergut E. H. 1989. *Polymer Handbook*, 3rd ed., pp. 435–449, Wiley-Interscience.
3. *Encyclopedia of Polymer Science & Technology*, 1985, 2nd ed., Vol. 2, pp. 176–186, Wiley-Interscience.
4. *Ibid.*, Vol. 3, pp. 467–472.
5. *Ibid.*, Vol. 3, p. 486.
6. *Ibid.*, Vol. 6, p. 545.
7. Kel-F™ 81 plastic, *Engineering Manual*, 3M Corp.
8. Baer E., *Engineering Design For Plastics*, Reinhold Publishing Corp.
9. Perry R. H., Green D. W., and Maloney J. O., 1997, *Perry's Chemical Engineers' Handbook*, 7th ed., pp 2–49.
10. Bhadha P. M. 1994. Control of moisture and contaminants in shielding gases, *Welding Journal* 73(5): 57–63.