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# Using Partial Pressure in Vacuum Furnaces

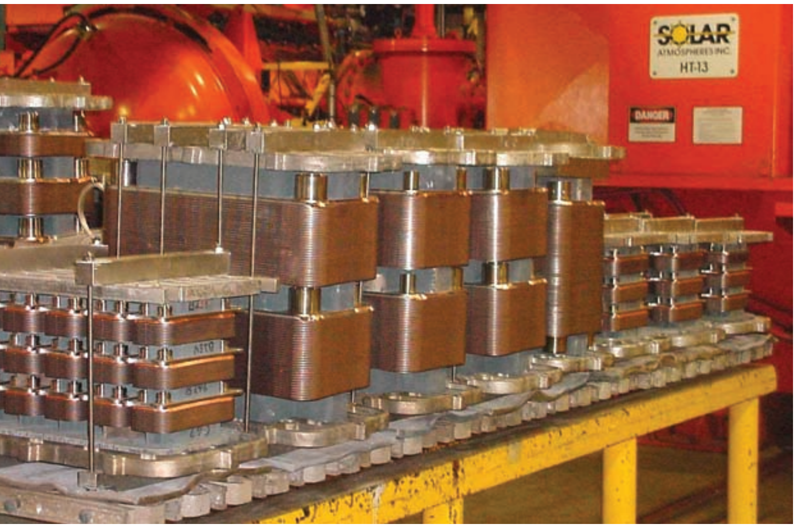
It is of primary importance to understand vapor pressure in the vacuum heat treatment of metals. Operating in vacuum can often lead to significant evaporation, or "boiling away," of elemental constituents in the materials being processed, affecting surface integrity and in some cases altering the chemical composition of the base (or filler) metal. One way to overcome this problem is to introduce a gas partial pressure higher than that of the material's vapor pressure. Different gas choices, introduction methods and controls are available to the heat treater. The natural questions are how and when should they be used? Let's learn more.

## Vapor pressure

The vapor pressure of a material is the partial pressure present in the atmosphere which surrounds it. In other words, the vapor pressure tells us how much vapor a material will produce; a high vapor pressure means that the material will readily evaporate. Every material has a characteristic vapor pressure associated with it, which varies with temperature; the vapor pressure increases with increasing temperature.

All metals evaporate as a function of temperature (first-order effect) and vacuum level (second-order effect). Equation 1 allows the determination of the evaporation rate ($Q$), and shows that the vapor pressure/temperature relationship is nearly logarithmic:

$$Q\mathrm{max} = 0.058 P\mathrm{v} \sqrt{\frac{\mathrm{M}}{\mathrm{T}}}$$




**Load of flat-plate heat exchangers ready for brazing at 5 torr nitrogen partial pressure at 1120˚C. Photo courtesy of Solar Atmospheres Inc.**

where $Q_{max}$ = evaporation rate (g/cm$^3$-sec), $P_v$ = vapor pressure (torr), $T$ = temperature (K) and $M$ = molecular weight.

In vacuum furnaces, metals tend to volatize at temperatures below their melting points. Table 1 shows this relationship for a number of common metals. The longer parts are held at the temperature and at the vacuum level shown, the greater the loss of the metallic element by evaporation. Where the element is part of a metal alloy system the vapor-pressure relationship changes (total vapor pressure of the alloy is the sum of the vapor pressures of each constituent times the percentage in the alloy, although this relationship has been debated by those knowledgeable in the field).

For example, processing aluminum, cadmium, magnesium, manganese and zinc or their alloys at temperatures as low as 400°C (750°F) may be marginally or totally impractical. This is why processing brass (Cu-Zn alloy) is normally not done in a vacuum system, or if it is, it is carried out at partial pressures near atmospheric. As the temperature increases, fewer materials can be run without being affected.

Stainless and tool steels and more exotic alloys often are processed in vacuum. Chromium present in these materials evaporates noticeably at temperatures and pressures within normal heat treatment ranges. Processed above 990°C (1815°F), chromium will vaporize if the vacuum level is less $1 \times 10^{-4}$ torr and the parts are held for a prolonged time. Heat treaters often observe a greenish discoloration (chromium oxide) on the interior of their vacuum furnaces, the result of chromium vapor reacting with air leaking into the hot zone. Otherwise, the evaporation deposit is bright and mirror-like. To avoid this, an operating partial pressure between 0.3 and 5 torr is typical for most chromium-containing parts.

For vacuum brazing (silver, copper, nickel), depletion of the filler metal alloy can be avoided by raising the pressure in the furnace to a level above the vapor pressure of the alloy at brazing temperature. For example, copper, having an equilibrium vapor pressure at 1120°C (2050°F) of $1 \times 10^{-3}$ torr is usually run at a partial pressure between 1 and 10 torr. Nickel brazing normally is done in the $10^{-3}$ to $10^{-4}$ torr range. However, in the $10^{-5}$ to $10^{-6}$ torr range, you run the risk of losing some nickel, which has an equilibrium vapor pressure of $1 \times 10^{-4}$ torr at 1190°C (2175°F).

## Which gases can we use?

Argon, hydrogen and nitrogen are the most common partial pressure gases. Often, argon is preferred as it tends to "sweep" the hot zone; that is, the heavy molecule tends to reduce evaporation compared with nitrogen and hydrogen. Specialized applications such as those in the electronics industry may use helium or even neon (if an ionizing gas is needed). Gases having a minimum purity of 99.99% and a dew point of -60°C (-76°F) or lower should be specified.

Certain cautions are in order. For example, nitrogen may react with certain stainless steels and titanium-containing materials resulting in surface nitriding. In the case of hydrogen, the normally near neutral vacuum atmosphere can be sharply shifted to a reducing atmosphere to prevent oxidation of sensitive process work or for furnace/fixture bakeout/cleanup cycles. Embrittlement by hydrogen is a concern for certain materials (e.g., Ti, Ta).

## Measurement and control

It is critical to know the exact pressure, flow and type of gas being injected into the vacuum furnace so the process being run is under control. Thermocouple gages typically found on vacuum furnaces are affected by gas species, because they are calibrated for air. It is not uncommon to believe, for example, that you are running an argon partial pressure at 1 torr when in reality you are running at 0.4 torr, or with hydrogen (or helium) that you are at 10 torr when you are really at 1 torr. Absolute-pressure gages, such as the BOC Edwards Barocel® (Wilmington, Mass.; www.bocedwards.com/industrial) should be used to determine precise partial pressure values.

For flow accuracy, flowmeters should have a micrometer needle valve installed in the downstream line. On many units, the gas is pulsed in using a solenoid valve and set-point control on the vacuum gage, similar to continuous flow with a needle valve installed. Also, it is extremely important to inject the partial pressure gas directly into the hot zone so the gas does not short circuit the work area.

Table 1 Vapor pressures for selected elements

| Element | Temperature (°C) at which specific vapor pressure (torr) exists | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0.001 | 0.01 | 0.1 | 1.0 | 10 | 100 | 760 |
| Al | 889 | 996 | 1123 | 1279 | 1487 | 1749 | 2327 |
| Be | 1029 | 1212 | 1367 | 1567 | 1787 | 2097 | 2507 |
| B | 1239 | 1355 | 1489 | 1648 | 3030 | 3460 | 2527 |
| Cd | 220 | 264 | 321 | 394 | 484 | 611 | 765 |
| Ca | 528 | 605 | 700 | 817 | 983 | 1207 | 1482 |
| C | 2471 | 2681 | 2926 | 3214 | 3946 | 4373 | 4552 |
| Cr | 1090 | 1205 | 1342 | 1504 | - | - | 2222 |
| Co | 1494 | 1649 | 1833 | 2056 | 2380 | 2720 | 3097 |
| Cu | 1141 | 1273 | 1432 | 1628 | 1879 | 2207 | 2595 |
| Ga | 965 | 1093 | 1248 | 1443 | 1541 | 1784 | 2427 |
| Ge | 1112 | 1251 | 1421 | 1635 | 1880 | 2210 | 2707 |
| Au | 1316 | 1465 | 1646 | 1867 | 2154 | 2521 | 2966 |
| Fe | 1310 | 1447 | 1602 | 1783 | 2039 | 2360 | 2727 |
| Pb | 625 | 718 | 832 | 975 | 1167 | 1417 | 1737 |
| Mg | 383 | 443 | 515 | 605 | 702 | 909 | 1126 |
| Mn | 878 | 980 | 1103 | 1251 | 1505 | 1792 | 2097 |
| Hg | 18 | 48 | 82 | 126 | 184 | 216 | 361 |
| Mo | 2295 | 2533 | 2880 | 3102 | 3535 | 4109 | 4804 |
| Nd | 1192 | 1342 | 1537 | 1775 | 2095 | 2530 | 3090 |
| Ni | 1371 | 1510 | 1679 | 1884 | 2007 | 2364 | 2837 |
| Pd | 1405 | 1566 | 1759 | 2000 | 2280 | 2780 | 3167 |
| P | 160 | 190 | 225 | 265 | 310 | 370 | 431 |
| Pt | 1904 | 2090 | 2313 | 2582 | 3146 | 3714 | 3827 |
| K | 161 | 207 | 265 | 338 | 443 | 581 | 779 |
| Re | 2790 | 3060 | 3400 | 3810 | - | - | 5630 |
| Rh | 1971 | 2149 | 2358 | 2607 | 2880 | 3392 | 3877 |
| Se | 200 | 235 | 280 | 350 | 430 | 550 | 685 |
| Si | 1223 | 1343 | 1585 | 1670 | 1888 | 2083 | 2477 |
| Ag | 936 | 1047 | 1184 | 1353 | 1575 | 1865 | 2212 |
| Na | 238 | 291 | 356 | 437 | 548 | 696 | 914 |
| S | 66 | 97 | 135 | 183 | 246 | 333 | 444 |
| Ta | 2820 | 3074 | 3370 | 3740 | - | - | 6027 |
| Sn | 1042 | 1189 | 1373 | 1609 | 1703 | 1968 | 2727 |
| Ti | 1384 | 1546 | 1742 | 1965 | 2180 | 2480 | 3127 |
| U | 1730 | 1898 | 2098 | 2338 | - | - | 3527 |
| V | 1725 | 1888 | 2079 | 2207 | 2570 | 2950 | 3527 |
| Zn | 292 | 343 | 405 | 487 | 593 | 736 | 907 |
| Zr | 1818 | 2001 | 2212 | 2459 | - | - | 3577 |

## Summary

Partial pressure atmospheres are required in many heat treating and brazing operations to achieve the desired results. Introduction of the partial pressure gas into the furnace hot zone at one or more locations and controlling the partial pressure injection gas stream as a continuous flow rather than trying to operate at a specific pressure are critical considerations. The choice of partial pressure gas is also important both from a cost and quality standpoint. **IH**

## Bibliography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Additional related information may be found by searching for these (and other) key words/terms via BNP Media LINX at www.industrialheating.com: vacuum furnace, vacuum heat treating, vacuum brazing, vapor pressure, partial pressure, evaporation rate.