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Why vacuum?

With this article—which outlines the benefits of vacuum processing—we begin a series dedicated to explaining key aspects of vacuum technology such as pumping, instrumentation, power supplies, and quenching. Later articles will detail applications well suited to vacuum.

by WILLIAM R. JONES

Heat treating and joining metals under vacuum was introduced in the late 1950s, but the vacuum processors were not really accepted until the 1960s and '70s. The change from conventional heat treating—atmosphere, salt, and so on—has continued since the 1970s, and, in fact, seems to be accelerating in recent years. One can safely predict that this trend will continue. With this article, an attempt will be made to underscore some of the basic reasons for this change.

In heat treating and brazing, "vacuum" means that practically all the air of atmosphere has been removed from the furnace hot zone. With modern mechanical vacuum pumps, vacuum blowers, and diffusion pumps, the basic vacuum of outer space (say, on the surface of the moon—10^{-5} to 10^{-6} torr) can be achieved quickly and in a matter of minutes.

However, it should be noted that once the furnace is pumped down for vacuum purge, reactive or neutral gases can be introduced for various operations and mixed, changed, or removed as required. This is often referred to as "partial pressure gas operation," and has been primarily used to prevent surface evaporation of higher vapor pressure elements, for example, copper or chrome. But combinations of gases like hydrogen, methane, and ammonia can also be introduced to the furnace hot zone in controlled amounts with gas flow meters, and the furnace operated from full vacuum to atmospheric pressure. This has allowed the vacuum furnace to compete with atmosphere furnaces, yet with gas purity and flexibility simply not otherwise available. Nitriding, carburizing, hydrogen scrubbing, and processing of normally easily-evaporated materials such as copper, and even brass, are a few examples of these applications today.

Typical cooling data
High-speed quench, N_2 gas at 15 psig
(2 atmospheres positive pressure)

7,500 cfm, 100-hp gas turbine blower

Part cross-section (3-inch length)	Cooling rate °F/minute 2000°F-1000°F range
1/2"	700
3/4"	650
7/8"	425
1-1/4"	400
2-1/4"	250

Based on 400- to 500-pound gross load.

Assume the parts are in open-type wire or rod baskets and reasonably distributed throughout the hot zone. Test thermocouple in drilled hole center of part. The following hardness data is approximate and varies with steel supplies.

Hardness data, as-quenched

Part cross-section (3-inch length)	Rockwell C scale
0 1 grade	
1/4"	64
1/2"	63
3/4"	62
1"	55
1-1/2"	55
4340 grade	
5/8"	55
7/8"	55
1-1/8"	53
2-1/8"	52
4140 grade	
1-1/2"	40
M1 or M2	
1/4"	67
1/2"	66
3/4"	65
1"	64
1-1/2"	63

With a vacuum heat treat environment, parts and components can be placed in a furnace and run through a process cycle without undesirable surface chemistry changes (oxidation) or scale development. For brazing, vacuum also means filler metals wet and flow easily. Furthermore, parts don't require the post-braze clean-up of flux or salt removal as they do with conventional processing.

Vacuum heat treated tool steel parts come out of the furnace bright, clean, and free of scale. This means salt removal and blasting operations are no longer needed, eliminating ecology (waste removal) problems. In some cases, reduced labor costs can pay off a new vacuum furnace in six months.

Annealing and solution heat treatment of stainless steel tubing, parts, and components fall into the same category. With conventional processing, pickling agents, blasting material, or sand residue in a hole or blind spot could cause major damage in subsequent operations such as tapping holes, galling, or scraping parts.

The vacuum furnace is fired from an electric power utility, and hence has no exhaust or flue gas. The furnace does not require power when idle; it is shut down cold when not in use and, thus, conserves energy and dollars. Since the furnace operates in vacuum not unlike a thermos bottle, energy loss is low; the furnace is

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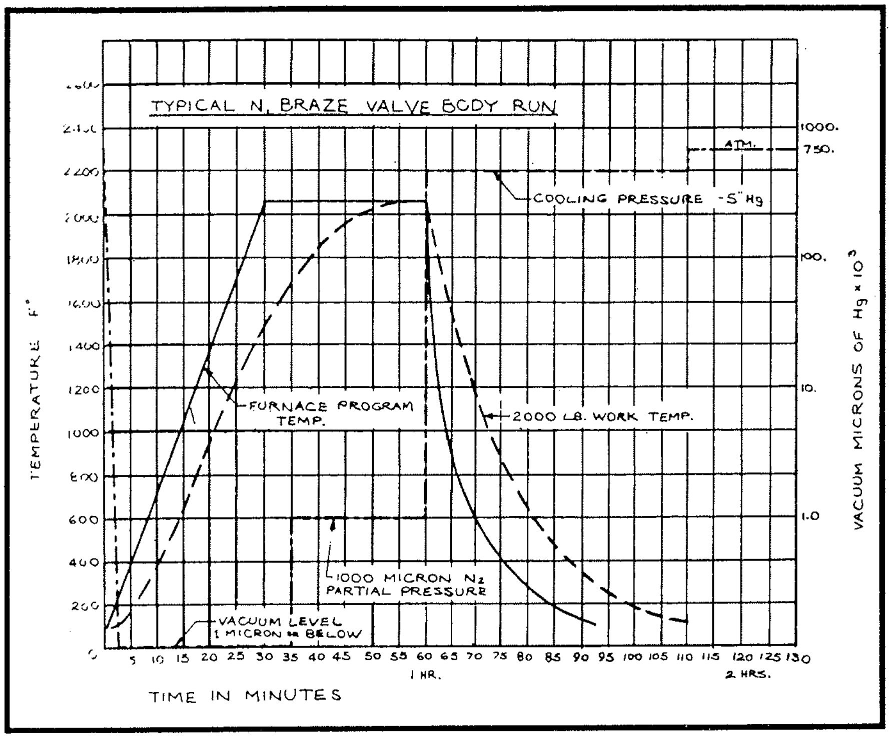
energy efficient. With the use of modern, saturable-core-reactor power transformers, solid-state temperature controls, and programmers, power and temperature control is practically infinite and fully automatic. It is even failsafe in the event of power, cooling water, and other utility losses. Most furnace vessels use a double-wall, recirculated-water-cooled design. This means operation in the front office or stock room is possible without risk of overheating buildings, material, or personnel. The furnace is, in this sense, "operator friendly."

Most vacuum furnaces are "batch" in operation. That is, the furnace is cold when loaded. It is then pumped down to vacuum, heated, quenched out with the inert gas, and unloaded. The operator is not exposed to a hot or dangerous flame condition. Hearth designs over the years have improved to where work loads of hundreds, even thousands of pounds can be loaded into the furnace and remain flat without concern for sagging or the part's "taking the shape of the furnace hearth." Graphite, molybdenum, and high-temperature ceramics have contributed to solving these problems, and are available for baskets and racks as well. Material handling techniques specifically for use with vacuum furnaces—from dedicated forklifts to automated carousels—have also been developed.

Unquestionably, the single most important advancement in recent years has been quenching. Once the work load is heated to temperature in vacuum, the furnace becomes an inert-atmosphere quenching chamber. At the end of the high-temperature soak the power supply is shut down, the vacuum system valved off, and the furnace chamber rapidly (in seconds) backfilled with nitrogen or argon gas. This gas is violently recirculated over the work load, then sent through a gas-to-water heat exchanger to remove heat energy, whence it goes back to the gas blower (turbine), and then returns to the work. Speed of product quenching is now approaching 1000°F per minute in some furnaces, which allows quenching and hardening of all the air-hardening tool steels, many of the oil-hardening alloy steels, and almost all of the stainless steel grades.



After sintering in vacuum, many of the powder metal alloys can be solution heat treated or hardened in like manner.

Rapid cooling is important for metallurgical reasons, but the vacuum furnace is also fast in terms of throughput—"floor-to-floor." In a 38-inch-deep furnace, a 1,000-pound work load can be heated to 2100°F, soaked out, and cooled to ambient in two hours. Work loads can be continuously cycled at this rate for days, and then the furnace shut down cold over a weekend or idle period. Restart is at will, with vacuum pumps and instrumentation taking 10-15 minutes to stabilize.

Over the last 20 years or so, other improvements have also been made in furnace technology. Heating elements and hot-zone insulation techniques have evolved as a result of experience and failures. Molybdenum and graphite heating elements can easily drive furnace operating temperatures to 2650°F, providing ample margin for routine processing temperatures. Molybdenum sheet and bar products, laminated graphite, graphite felt, and alumina felt all have contributed toward efficient, uniform-temperature hot zones, which stay together over years of operation. A vacuum furnace hot zone takes enormous stress from rapid heating and cooling through repeated cycles, because vacuum is by nature a batch process. Nevertheless, modern furnace hot zones in high-production applications can live through five years without requiring major repairs.

A critical requirement for the vacuum furnace is freedom from atmospheric or cooling water leaks. Since vacuum pumps have little pumping speed in terms of atmospheric gas flow, vacuum leaks have been, and to some extent remain, a plague to the industry. However, with correct welding technology for the basic vacuum chamber and the use of good seal design, such as "O"-rings, and high-temperature materials such as silicon or teflon, most of these problems are eliminated or minimized. Furnace leak rates today are low—in the range of 2 to 5 microns per hour—for properly maintained equipment. Gas backfill lines must be bubble-tight, with adequate gas reservoir tanks to prevent surges or even evacuation of inert gas delivery systems. **HT**