Vacuum furnaces with high pressure charge cooling

SECO/WARWICK is a successful supplier of horizontal and elevator vacuum furnaces for the tool and die and aviation industries, as well as commercial providers of hardening services. These furnaces feature a heating chamber with a special design suitable for modern industrial needs. Process flexibility is a critical requirement for vacuum furnaces in the typical manufacturing environment, as Josef Olejnik, SECO/WARWICK (Poland) Ltd in Swiebodzin describes.

A furnace should be capable of hardening critical steel loads or charges with critical sections (or both). For optimum performance, the furnace must operate with rapid and uniform heating and cooling capability.

The cooling rate of vacuum furnaces is an important parameter of the furnace design. Improvement of the heat treatment process is usually related to cooling uniformity and rate. Today, standard customer requirements also include isothermal quenching and convection heating capability – in automatic cycles – to enhance furnace performance. In industrial applications, besides the cooling rate parameter, the uniformity of cooling should be considered.

Vacuum furnaces with both cylindrical chambers (photos 1, 3 and 6) and rectangular chambers (photo 2) are available from a variety of suppliers. In furnaces with a cylindrical chamber, heating elements are arranged around the charge and the cooling system is designed in the form of jets spaced 360° around the charge. Furnaces with a rectangular heating chamber are usually designed with a reversible cooling system, from opposite sides (at least top/bottom). In a reversed cooling system, the gas flows in through the entire hatch cross-section, over and under the charge. In a typical design, with hatch cross section comparable with charge cross-section area, it is almost impossible to obtain uniform linear velocity through the charge cross section (plane 'a' in fig 1). Therefore, in practice, shutters and other elements to disrupt and direct the gas stream are used so that, with reversible gas flow to the load, acceptable uniformity of gas flow can be ensured and, thereby, uniform charge cooling rate t (though 20 – second cycles of gas flow reversion, by its nature causes non-uniformity of gas flow).

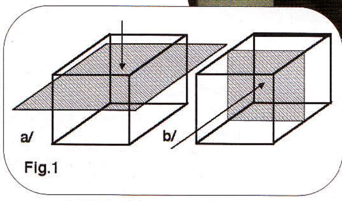


Fig 1. a / b inflow planes

Low gas inflow velocities result in a large portion of circulating gas being forced through the space between the load and heating chamber walls, which prevents obtaining high gas velocities within the charge. Dense packing of the load improves uniformity of gas flow through the charge, while an incomplete charge or a charge consisting of individual parts results in poor uniformity of flow. It is well known that the cooling rate (heat transfer coefficient α is equally dependent on gas linear velocity w (m/s) and cooling gas pressure p (bar), according to the formula:

$$\alpha = C\, w^{0,7}\, p^{0,7}\, \eta^{-0,39}\, cp^{0,31}\, \lambda^{0,69}$$

where: $\eta - c_p - \lambda$ identifies the cooling gas (its heat conductivity, specific heat and density).

The flow of gas mass through a large horizontal section area results in low linear velocities, which means that the gas mass flows partially outside the charge volume around its periphery. The linear velocity may be improved through installation of a high volumetric delivery fan, used in the critical part of the cooling cycle, to solve the problem, but this is an awkward solution involving the substantial increase of fan motor power rating.

Designs of this nature are effective in the case of smaller furnaces, with useful space dimensions up to 600 x 600 x 900mm. Among manufacturers, there was a well-founded opinion that a rectangular chamber is much less labour consuming than a cylindrical chamber, hence, it could be offered at a cheaper price. In the European market, it is also important that, by large, all manufacturers of vacuum furnaces with rectangular chambers offer an option of convection heating relevant to flexible and efficient furnace utilisation.

In the case of SECO/WARWICK, both premises are immaterial, as the manufacturing cost of a cylindrical chamber is similar to that of a rectangular chamber, offered by competitors and, moreover, the company has been successfully employing convection heating systems ▶

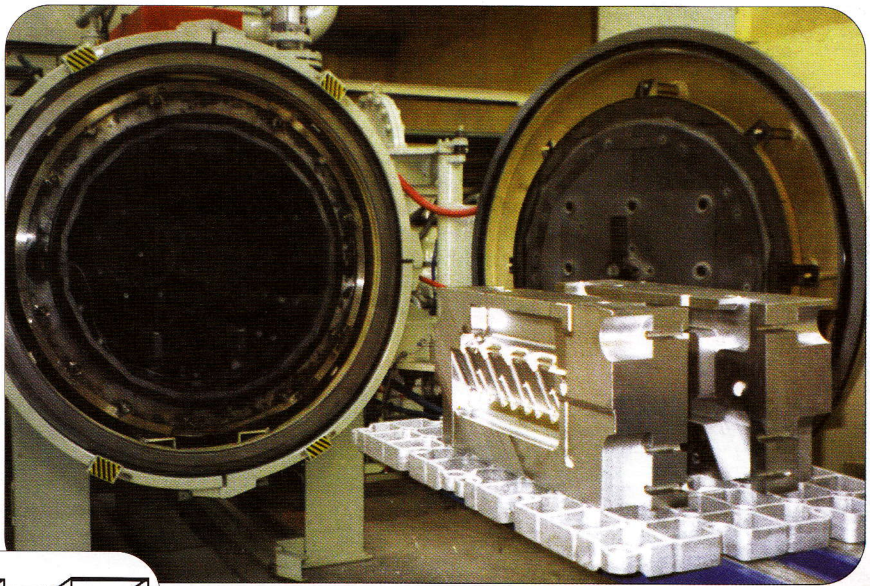


Photo 3. HTC die

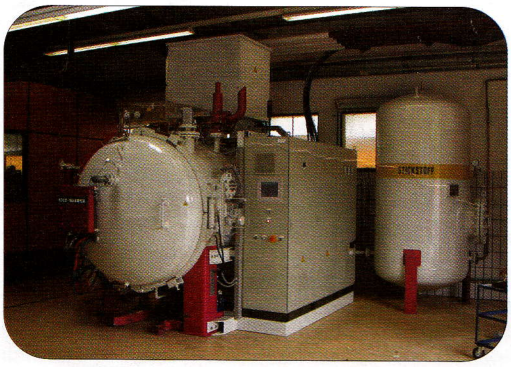


Photo 1. SWL round furnace

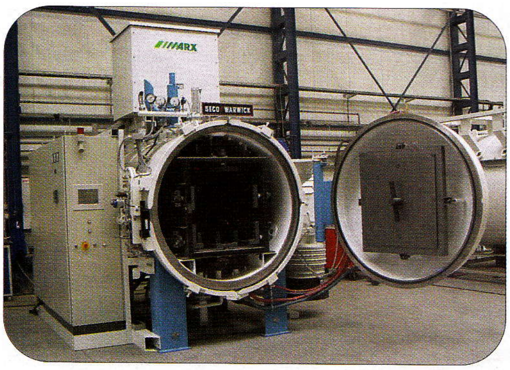
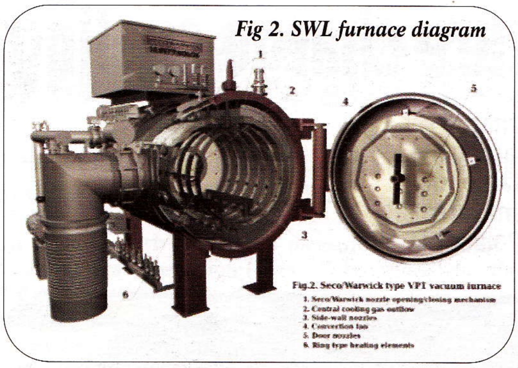


Photo 2. Square furnace

THE COOLING RATE OF VACUUM FURNACES IS AN IMPORTANT PARAMETER OF THE FURNACE DESIGN. IMPROVEMENT OF THE HEAT TREATMENT PROCESS IS USUALLY RELATED TO COOLING UNIFORMITY AND RATE. TODAY, STANDARD CUSTOMER REQUIREMENTS ALSO INCLUDE ISOTHERMAL QUENCHING AND CONVECTION HEATING CAPABILITY – IN AUTOMATIC CYCLES – TO ENHANCE FURNACE PERFORMANCE.

Fig 2. SWL furnace diagram



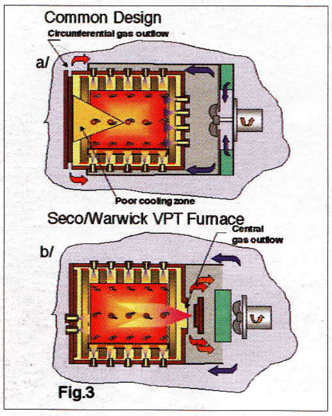


Fig 3. Suction zones

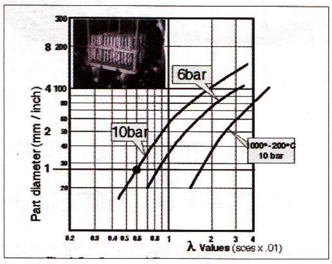


Fig 4. Bar cooling test. Cooling capabilities (800-500°C) for furnace 600x600x900mm in nitrogen (or cooling times Load 1000°-200°C

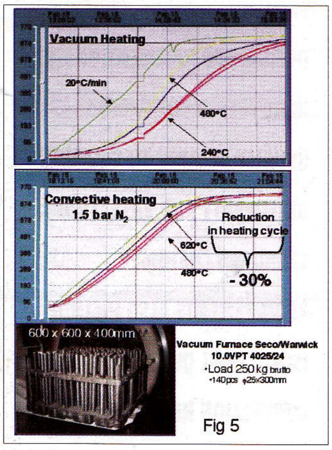


Fig 5. Convection heating

in cylindrical chambers for eight years, in scores of applications. Hence, in spite of SECO/WARWICK's ability to provide rectangular chambers, in most cases, furnaces with round chambers are supplied because they are the best choice to meet customer performance requirements.

Due to their nature, furnaces with jet gas cooling systems provide uniform flow of cooling gas mass to the charge surface, where the linear velocity of gas flow from jets is slowed down (See diagram, fig 2 and photo 1) and the gas is conveyed through the charge along its axis and thereby through the 'b' cross section (fig 1) smaller than in the case of a rectangular furnace. This maintains much higher gas linear velocities within the charge. Therefore, this design achieves the highest cooling rates. The basic concept of the SECO/WARWICK design is to create gas inflow through a system of jets spaced around the charge in the cylindrical wall of the heating chamber and in its front-end wall. The gas flows out through a hatch in the back end wall. Based on its extensive experience, it can state that uniformity of cooling depends on the set-up of the zone of the gas outlet from the chamber. A simple design solution is to situate this zone on the circumference of the contact surface of the chamber cylinder with the wall (fig 3a). In this solution, the gas flow is not in the charge axis over its entire length, which besides a very good gas flow velocity value, causes some non-uniformity in the gas flow.

In the SECO/WARWICK solution, (fig 3b) the gas suction zone is located in the charge axis, which maintains the axial flow over the entire charge length and volume. The company has developed this design, ensuring maximum cooling rate and cooling uniformity.

Fig 4 shows cooling test results of carbon steel bars, at 10 bar pressure, in nitrogen, in 600 x 600 x 900mm furnace. The test charge consisted of 200 dia 25 x 300mm bars, of 340kg net weight.

For such charges, λ coefficient at 0.6 level was obtained. It is obvious that cooling is always related to some non-uniformity. Also with this charge, some cooling non-uniformity was observed; with the above cooling rate $\lambda = 0.6$, max temperature non-uniformity in the above charge was obtained at 90°C. For comparison, in the best design with reversible cooling a similar course was obtained but at $\alpha = 0.8$.

These furnaces are particularly useful for hardening moulds and dies, in accordance with NADCA recommendations and GM DC-999-1 standards (photo 3). The latter requires that the cooling rate at the thermocouple location (5/8in below charge surface) be min 30°C/min. for a 406 x 406 x 406mm die (16in cube) and net weight of 530kg, at min pressure of 9 bar N_2, in temperature range from austenite – forming temperature of 1,030°C to 540°C.

In such applications, 600 x 600 x 900mm and 900 x 800 x 1,200mm furnaces are most commonly used. Tests, carried out at a pressure of 9 bar N_2 in 600 x 600 x 900mm furnace (Photo 4) showed an average cooling rate of the order of 80°C/min. (for five sides of the block) and at the level of 50°C/min in 900 x 800 x 1,200mm furnace (photo 5).

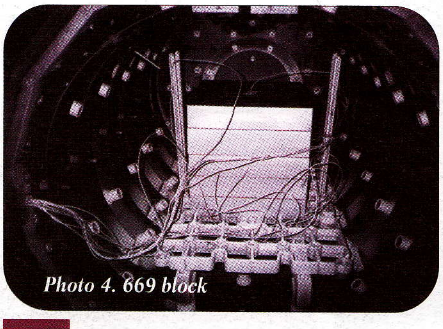


Photo 4. 669 block

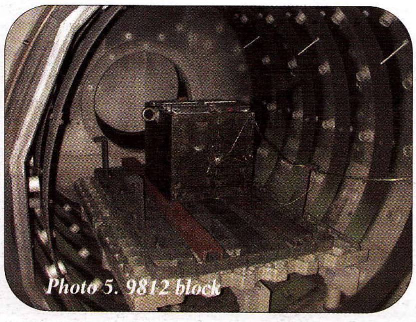


Photo 5. 9812 block

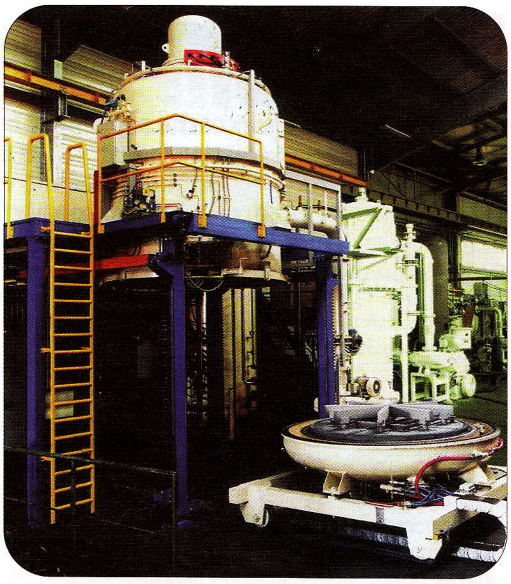


Photo 6. A 1,500 x 1,500mm dia elevator furnace with in-built convection heating system, based on a SECO/WARWICK design for a round heating chamber

A comparison of both photos indicates a much higher degree of packing of the charge in 600 x 600 x 900mm furnace chamber, which means a much higher actual linear gas flow velocity. Improved cooling rates are achieved simply by treatment of the charge, consisting of many parts, or by using a higher pressure of cooling gas, eg 12 bar.

Though GM standard requires a minimum cooling rate at 28°C/min level, practitioners indicate an essential effect of this rate on the number of possible working cycles of heat treated mould or die.

For this type of process, SECO/WARWICK supplies standard furnaces 600 x 600 x 900mm, 900 x 800 x 1,200mm and 1,000 x 1,000 x 1,500mm, with maximum cooling gas pressure up to 12 bar N_2.

Cooling rates with 10 (12) bar pressure are important primarily in the upper temperature range. For HSLA steel, it is sometimes required that this rate be maintained up to 200°C. Fig 4 shows the course of cooling. It appears that the time continues to be short. Therefore, most furnaces are currently equipped with fans with water-cooled motors that are considerably overloaded during the first 10min of the cooling cycle.

Supplying power to the fan motor by inverter offers a new technological potential of cooling the charge in helium, in a 10 bar furnace, at rates $\lambda < 0.6$. As helium requires much less load, it allows the motor to run at approximately 4,500rpm, thus permitting a heat transfer coefficient as low as 0.3. It is possible to obtain a coefficient of 0.6 with nitrogen and 0.3 with helium in a straightforward operation. This furnace design allows SECO/WARWICK to offer a system of vacuum carburisation with the option of gas quenching of high-alloy carburising steel.

In production practice, it is always important to support charge heating in low temperatures with convection heating. SECO/WARWICK has successfully used, for many years, a well-proven convection heating system in furnaces with cylindrical heating chambers. The combination of this system with heating elements of large surface area and low surface load allows rapid and uniform heating of particularly densely packed charges. Fig 5 shows the comparison of heating test results in vacuum exclusively and with convection heating. The reduction in cycle time for cooling is evident.

SECO/WARWICK incorporates convection heating systems in horizontal and elevator furnaces. This is standard equipment for furnaces of 6 and 10/12 bar furnaces with graphite insulation. Sometimes, such systems are incorporated into (15) bar furnaces.

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