Debinding and sintering solutions for metals and ceramics

Proper removal of organic binders and lubricants is critical if the required properties are to be attained in sintered metal and ceramic parts. Scott K. Robinson and Matthew R. Paul of Centorr/Vacuum Industries (Nashua, NH, USA) consider the issues involved in debinding different materials, and detail the design and operation of various vacuum and controlled atmosphere debinding processes developed by the company. They also briefly discuss hot zone designs for common sintering processes for both batch and continuous furnaces.

In various metals and ceramic forming processes involving sintering, whether it is injection moulding, isostatic pressing, hot pressing, powder compaction or slipcasting, organic binders are used to hold powders together. For powder compaction organics are also added in the form of lubricants – small fatty acid based materials such as Acrawax® or zinc stearate used for die wall lubrication and internal powder-to-powder lubricity.

While many companies are involved in optimizing these waxes and polymer plastics for high performance applications, in the sintering business we destroy these additives, trying to remove every trace of their existence during a debinding step prior to reaching final sintering temperatures. In some cases, as with metal injection moulding (MIM), the binder must be entirely removed from the compact or the residual carbon content may form a eutectic with the metal alloy at sintering temperatures causing melting at lower temperatures than desired, with low density and crystallization as the results. With ceramics and hardmetals the opposite is sometimes true as carbon containing binders are used with the intent of supplying carbon content during sintering to attain a stoichiometric formulation.

Here we discuss the debinding processes for powdered metals (PM), hardmetals, ceramic/metal injection mould-ing and ceramic forming. Because of the design of vacuum/controlled atmosphere furnaces, which typically require metal radiation shields or graphite insulation, the use of oxygen atmospheres during debinding is precluded as it will damage the hot zone. With some oxide or nitride based ceramics such as alumina, zirconia and aluminium nitride, common refractory lined oxygen furnaces are used to thermally combust the binder. In the presence of air, the carbonaceous binders burn readily and more completely than they would in a blanket of inert gas. Unfortunately, most metals and non-oxide ceramics would react with oxygen even at the lower temperatures found in debinding, forming oxide coatings, which are difficult to remove later on during sintering.

Debinding methods

The selection of lubricants and binders commonly used in metals and ceramics processing are summarized in Table 1.

To handle this large variety of materials you need a variety of debinding methods. The most common methods are summarized in the sidebar.

Vacuum dewax for hardmetals

Developed over 20 years ago, vacuum dewax was the first process to allow debinding and sintering of hardmetals in one furnace, saving production time and capital expense. By using a vacuum and leveraging the low vapour pressure properties of the paraffin wax binder, a fast and efficient debinding process was developed, when compared to positive pressure thermal debinding.

Vacuum dewax uses low vacuum levels (typically 10^{-1} to 10^{-2} torr), and low temperatures, to evaporate paraffin wax off the load. By bringing off the wax at temperatures below the cracking point there is less chance of unintentional carbon pickup. There is no retort in the furnace so the wax by-products must diffuse through the graphite felt hot zone insulation to get to the outer water-cooled shell where the wax immediately condenses and solidifies on the casing. To reduce this buildup, units were fitted with both cold and hot water flow in the jacket so the

Table 1: Typical binders and lubricants used in metal and ceramic powder processes

Process	Binders & lubricants
Powdered metals	Acrawax® C; zinc &lithium stearates
Metal & ceramic injection moulding	Paraffin wax; polymers (PE, PP); agar; polyacetal; water soluble polyvinyl alcohol
Ceramics processes	Methylcellulose; phenolic resins; polyvinyl acetate, polyvinyl alcohol; acrylics; caoutchouc glue; polymethyl methacrylate; colloidal silica

casing could be run above 60 °C causing the solidified wax to liquify and flow to the bottom of the tilted chamber where it runs into a wax cup reservoir (Figure 1).

At the end of each process cycle a hot water flush is run on the chamber walls to make chamber cleaning easier and faster. The balance of the wax leaves the furnace chamber through the roughing vacuum manifold to a wax condenser with the exhaust passing through to the pumping system. The vacuum level is not controlled in any way other than to operate at the ultimate vacuum of the pumping system (typically 0.1-1 torr against the offgas load). For different binders, the wax condenser can be replaced with other types of traps such as chilled liquid nitrogen vessels with baffled plates.

The main disadvantage of the vacuum dewax process is the fact that the evaporating wax must flow past the elements and insulation to exit the hot zone. Since the heating elements can be up to 100 °C hotter than the load temperature, cracking of the paraffin wax can occur as the wax-laden vapours comes in contact with the elements forming a carbon-rich environment (which is usually considered in the part formulation) (Figure 2).

The other major disadvantage is that, over time, the wax infiltrates the graphite felt lining. Later in the process

Summary of debinding options available from Centorr/Vacuum Industries

| Debinding method	Materials	Binder	Removal technique	Advantages	Disadvantages
Vacuum Dewax	WC	Paraffin wax	0.1 torr partial pressure during debinding	Low cost equipment.	Longer cleanup time due to wax buildup in chamber. Shorter hot zone element and insulation life. Less carbon control due to cracking of wax during debinding.
Sweepgas (WC)	WC	Paraffin wax	1-10 torr partial pressure with argon sweepgas flowthrough	Less furnace maintenance and cleaning. Increased hot zone insulation and element life. Removes wax from hot zone before it can come in contact with elements and crack. Ensures constant vacuum level during debinding regardless of the amount of binder coming off.	Could require change in customer's formulation due to removal of more carbon during debinding. Expense of additional equipment including vacuum sensors, gauges, valves. Uses small quantities of inert gas during binder removal.
Sweepgas (MIM/CIM)	17-4 PH 316-L Carbonyl iron Tool steels Ti, Ti6Al4V superalloys	Wax/PP, PE, polymer Agar Polyacetal Various	10-500 torr partial pressure with sweepgas flowthrough *or* positive pressure inert gas/H_2 flowthrough	Precise gas flow over each individual tray and part ensures complete binder removal. Allows partial pressure or positive pressure binder removal with Ar, N_2 and H_2 gases. Higher partial pressures (100-300 torr) provide better heat transfer mechanism than pure vacuum environment for debinding, but result in longer debind times.	Expensive furnace design.
Injectavac (MIM)	17-4 PH 316-L Carbonyl iron Tool steels Ti, Ti6Al4V superalloys	Wax/PP, PE, polymer Agar Polyacetal Various	10^{-3} to 10 torr wax diffusion pump debinding followed by 10-300 torr sweepgas polymer removal	Inexpensive design for MIM processing with low annual operating costs, compared with metal hot zone furnaces. Capable of sintering most stainless steels, even those with requiring low carbon contents. Heavy wall graphite retort with staggered shelves and integrated gas plenum for consistent gas flow dynamics and efficient binder removal. Robust once-through oiling mechanical rotary vane pump and blower.	Cannot be used for some special alloys or titanium alloys due to carbon control.
Positive pressure debinding (inert gas/hydrogen)	WC MIM Powdered metals Ceramics	PEG PVA/PVOH Acrawax® Stearates Phenolics	0-2 psig positive pressure flowthrough (Ar, N_2 or H_2)	Reducing atmosphere provides complete combustion of organics. Positive pressure 'bathes' parts in inert gas for better uniformity. Heated gas flow results in no cold spots. Incinerator results in complete combustion of VOCs.	Optional propane tower not 100% effective for tough, tarry binders, which require longer residence time. Expense of hydrogen system. Expense of thermal incinerator.
Continuous furnace thermal debinding	SiC Si_3N_4 AlN Electronic ceramics	Methylcellulose Phenolics Epoxies PVA/PVOH	Atmospheric debind	Capability of handling tarry, sticky binder systems in high volume.	Routine maintenance required on continuous system.
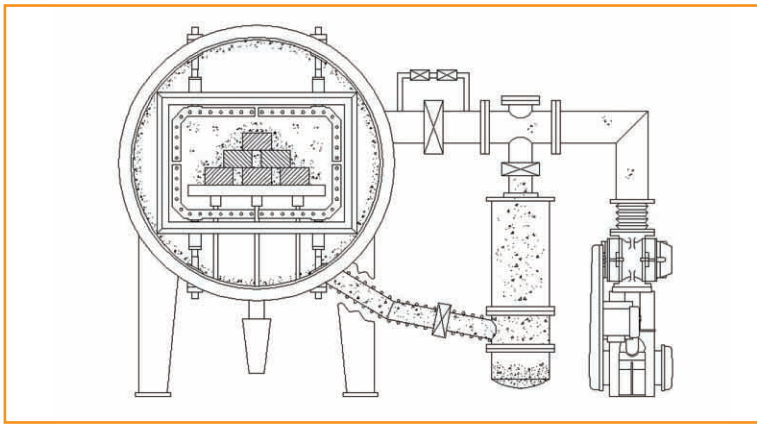
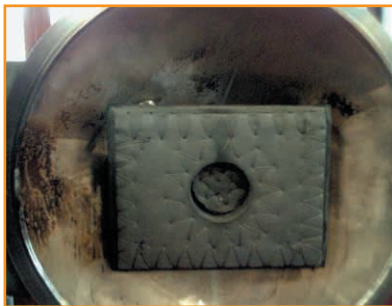Figure 1: Vacuum dewax system for delubing hardmetals.

Figure 2: Discolouration on chamber walls signifying cracked wax.

cycle during sintering, the insulation is subjected to much higher temperatures where the condensed wax becomes gaseous (Figure 3) and again cracks due to the high temperature adding even more carbon to the system. This is typically not desired. The felt also stiffens over time as the carbon particulate solidifies in the felt increasing its density and eventually reaching the point where its thermal conductivity increases causing it to become a less effective insulator. Eventually the hot zone will no longer be able to achieve desired ramping rates with a full load during sintering and may even fail to attain maximum temperatures.

Sweepgas™ for hardmetals
To meet the industry's need for improved productivity and lower maintenance costs, Centorr/Vacuum Industries developed Sweepgas technology for debinding.

In this design, a graphite retort is inserted into the hot zone in an effort to retain all the offgassing taking place, and create a barrier through which the paraffin cannot return. A special graphite pumpout tube with optical baffles (to prevent heat loss out the opening) connects the
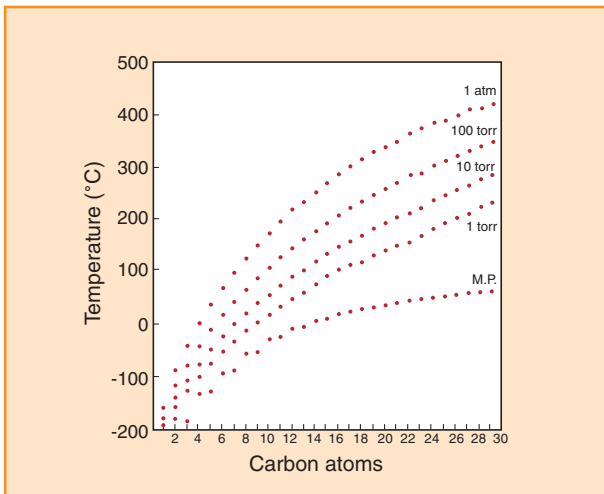

Figure 3: Vapour pressure and melting point of the C1 to C29 normal paraffins.
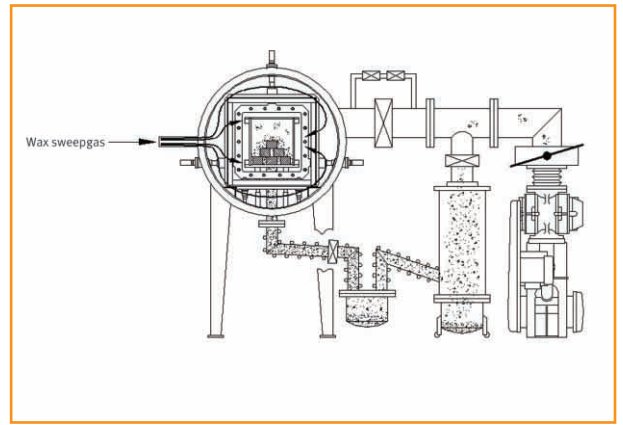

Figure 4: Sweepgas process for delubing hardmetals.

retort directly to the condensing trap and pumping system. CFC tubes can be used to lower the heat loss out of this port by as much as 25%, improving furnace uniformity (Figure 4).

In order to improve the wax collection and speed up debinding time, an argon sweepgas is used as a carrier gas. Because of the added gas load, vacuum levels of 10^{-1} torr are no longer possible.

Figure 5: After the Sweepgas cycle little or no wax buildup is observed on the chamber walls.

The system introduces a measured flow of inert gas into the chamber which diffuses into the graphite retort 'sweeping away' binder offgassing. The system is designed to operate at pressures of about 8 torr in the retort and 10 torr in the chamber while trying to ensure a 1-2 torr differential between chamber and retort. This pressure 'head' outside the retort minimizes the escape of wax vapour into the chamber (Figure 5). The binder-laden gas is pumped out the bottom of the retort through a graphite pumpout tube. A closed-loop controller takes the pressure signal input from the retort capacitance manometer and the output automatically adjusts the electro-mechanical modulating valve to regulate pumping speed and provide constant pressure control within the retort during debinding. The binder is trapped in the condensing system before reaching the vacuum pumps.

While sweepgas furnaces still include hot and cold water manifolding, newer units do not require hot water circuits on the chamber; due to the efficiency of the debinding system, only the wax condenser is plumbed with hot water to allow for cleaning at the end of a cycle.

The heart of the sweepgas system is the wax condenser. Older designs used the Lutts and Anderson style (Figure 6). Here, low pressure carrier gas plus binder first enter an empty wax pot through a heated/insulated debind manifold. When the wax molecules enter this large volume cavity, a portion immediately condenses out due to the change in pressure, leaving a majority of the wax condensate in the pot.
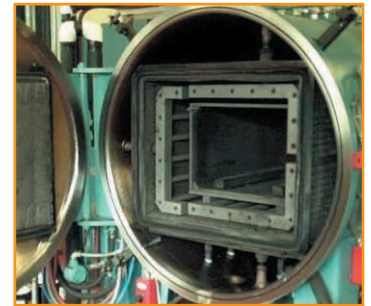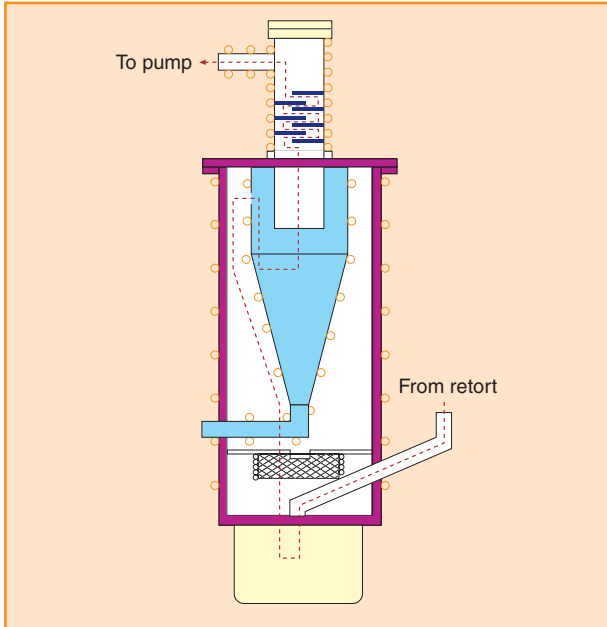
Table 2: Wax recovery results in laboratory trials

	Vac Dewax	Sweepgas
Collection in chamber	69%	<2%
Collection in condenser	15%	95%
Total	84%	97%

Figure 6: Sweepgas condenser (after Lutts and Anderson).

The remaining vapour passes through a heated bronze wool mechanical filter where additional wax condenses out, dripping down into the pot below.

To remove the smaller diameter wax particles, filters will not work unless they are so restrictive that they reduce the pumping conductance excessively. So, after the bronze wool filter, the gas passes through a restrictive orifice causing a vortex-type flow around a water-cooled cylindrical cone. The centrifugal force causes the particles entrained in the gas flow to migrate to the outer walls due to their higher momentum. If the inner and outer walls of the condenser are then water cooled, this cyclone effect causes significant condensation of all but the smallest wax particles. Lastly the vapour passes through an optically dense path of water-cooled 'D' baffles causing even small particles to condense and adhere to the chilled surfaces.

For larger hot zones, a newer modified sweepgas condenser has been developed which allows for a reasonable pressure differential in larger size hot zones without requiring excessive sweepgas flows and correspondingly larger pumping systems (Figure 7).

This style condenser is similar to the Lutts and Anderson design, except that the cyclone chamber is replaced with dual mechanical filtration media. The first chamber holds a basket of lightweight high surface area aluminium stampings called pall rings. The upper basket is filled with a finer stainless steel wool media. Both baskets are removable for easy cleaning with a heat torch, steam or solvent bath. These condensers are cleaned at the end of every cycle by running a hot water flush on the jacket causing the trapped wax to liquify and melt dripping into the pot below.

The bottom pot is emptied after every cycle or at least weekly based on the percentage of binder in the load. The condenser body is typically cleaned once per quarter.

Only with efficient wax trapping can you expect to have reliable and consistent pump performance with little binder residue entering the pump chamber and contaminating the oil. Time between oil changes is typically between 30-50 cycles for mechanical pumps and up to 200 cycles for the roots blower. Due to the efficiency of the trap, more expensive pumping designs, such as liquid ring or dry pumps, can be avoided for these binders.

Table 2 compares the efficiency of the older vacuum dewax process and the newer sweepgas technology.

The sweepgas technique's primary advantage is the lower amount of wax buildup in the furnace chamber which must be cleaned after every run. Hot zone life is also improved due to preventing wax infiltration/reaction with the insulation and elements. Caution should be taken before considering a change from vacuum dewax to sweepgas, however. While the advantages are worthwhile, and cost effective, many carbide producers find that they need to reformulate their powder mix due to the lower carbon contents resulting from the more efficient binder removal.

Injectavac™ BRS™ process for MIM

Pioneered by Centorr/Vacuum Industries in the early 1980s, the Injectavac process was one of the first integrated debind and sinter processes for the growing metal injection moulding (MIM) market. Early research by S. Kennedy and C.W.P. Finn documented the problems in removing the large quantities of binders found in MIM feedstocks. The most common formulation consisted of a paraffin wax first stage, a polymer second stage and surfactant surface agent. Centorr/Vacuum Industries' experience in wax removal from tungsten carbide proved helpful, but the large quantities of wax proved too much for the condenser trap. Improved gas flow dynamics were also required in order to sweep away this large volume of binder. The second stage polymer proved equally difficult to handle, as the material did not act as a wax (which condenses back in its original state). The high molecular weight polymer is essentially a plastic, and therefore has a high vapour pressure making the vacuum level inconsequential. The thermally
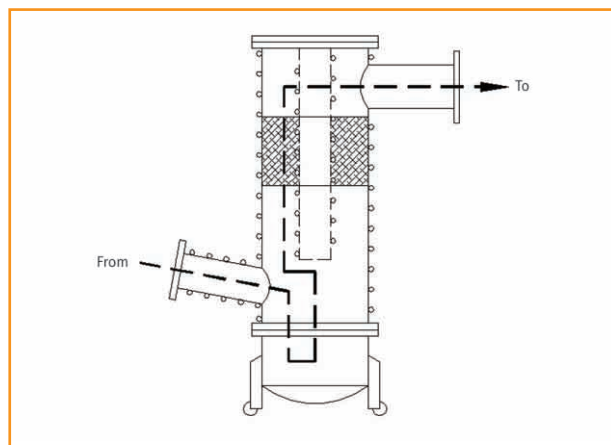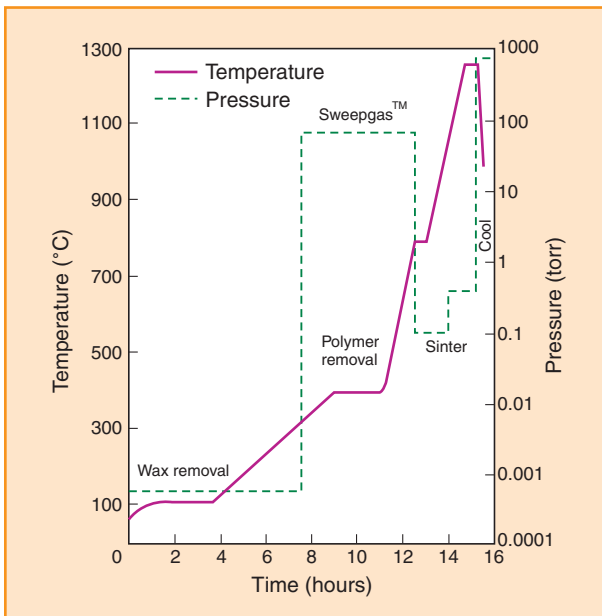

Figure 7: New 'Griffin' sweepgas condenser.

Figure 8: Typical binder removal and sintering cycle for an Injectavac™ furnace.

Figure 9: Effect of vacuum level on typical MIM binder removal times.

decomposed polymer breaks down into CO, CO_2 and low molecular weight hydrocarbon gases which form small diameter 'smoke-like' particles. Finn and others found this material difficult to trap in conventional cold traps, and hence developed the Injectavac BRS (Binder Removal System) process.

The hot zone in an Injectavac™ furnace incorporates a graphite retort design and modified sweepgas system similar to that used in tungsten carbide vacuum dewax. The difference, however, is that there is a pumpout tube in the bottom of the retort penetrating through the hot zone, allowing the evaporated wax to be removed to the chamber annulus without having to pass through the hot zone insulation or elements. The sweepgas is also plumbed directly into a box plenum at the rear of the retort (not into the chamber), and is only used during second stage polymer removal (not during wax removal). This plenum both preheats the gases and ensures consistent gas flow over all the trays in the work load.

To remove the large volume of wax (up to 30-40 vol%), a diffusion pumping system is included with large diameter port to achieve vacuum levels down to 10^{-3} to 10^{-4} torr during debinding allowing for fast evacuation of the paraffin wax at lower temperatures (Figure 8). No modulating valve or vacuum sensors are used for controlling vacuum levels: the pump is simply allowed to pump to its best vacuum level. As the wax passes through the diffusion pumping system the 'jetting' oil particles knock down the wax vapour forcing it through the heated foreline manifold onto the binder removal pump. While the wax does not contaminate the diffusion pump or its oil, some customers prefer to simply use the mechanical OTO pump during the wax removal stage and only use the diffusion pump during sintering if required.

Figure 9 shows the effect of using lower vacuum levels on the debinding time, which is the key advantage of the Injectavac design.

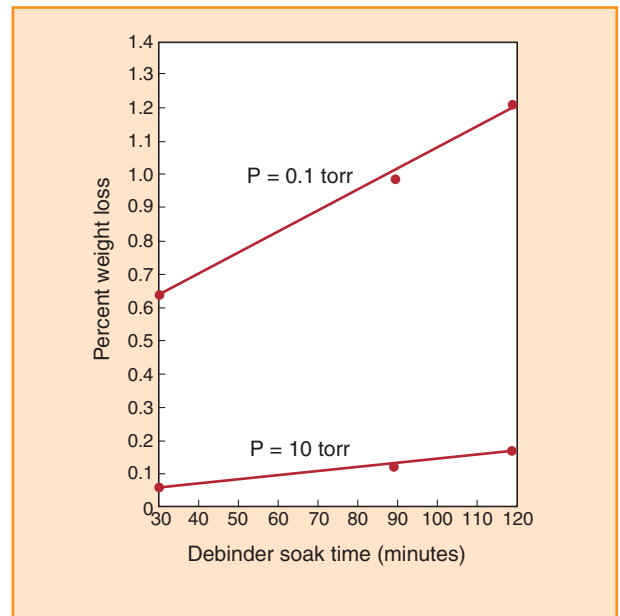As with the vacuum dewax process, the chamber is plumbed with both hot and cold water to allow the jacket to be heated above the wax melting temperature, and the chamber is pitched on a 3° tilt allowing the wax that collects on the walls, and bottom of the chamber, to flow into a manually valved wax reservoir pot with spigot.

The workhorse of the system is the specially designed mechanical pump/blower combination for wax/polymer binder removal. It consists of a Busch BRS™ once-through oiling pump, which continuously supplies fresh, clean oil to the compression chambers rather than recirculating oil from a sump. The oil, common SAE 40 non-detergent grade motor oil, does not remain in the pump long enough for binder contamination to be a problem. After passing through the pump, the oil is discharged to a collection container and the binders/polymers that would normally contaminate the oil (or build up in the pump) pass through with the oil and are continuously discharged. In addition, the oiling technique enhances bearing and seal lubrication for long trouble-free pump operation.

Critical second stage polymer binder removal is accomplished using a traditional Sweepgas technique where inert gas is bled into the gas plenum retort where it entrains polymers vaporized from the work pieces and carries them out towards the BRS system while maintaining quality operations. The simplicity of the system is that there are no traps to clog and no filters to clean or replace. The thoroughness of the binder removal allows for the successful processing of low carbon stainless steels such as 316L and 17-4PH in a graphite hot zone. The system combines this efficient binder removal with the lower initial investment of a graphite furnace, and lower operating and maintenance costs.

Sweepgas™ for MIM

Due to the tight process windows found in the MIM industry and a desire for higher levels of cleanliness, metal hot zone designs have become increasing popular for processing MIM components. To capitalize on this growing market segment Centorr/Vacuum Industries developed
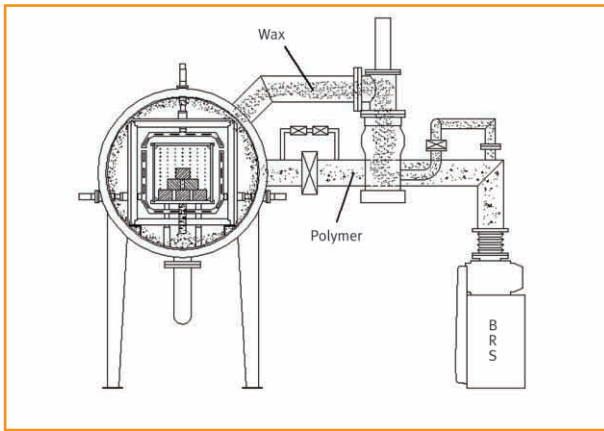
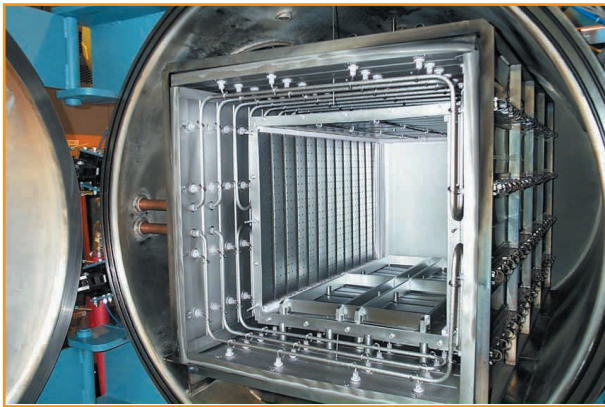**Figure 10:** Injectavac™ BRS™ process for debinding MIM components.

Figure 11: MIM molybdenum retort with integrated gas plenum for consistent gas-flow dynamics.

a new line of furnaces, the MIM-Vac™, based on their successful Workhorse metal hot zone furnace design.

Because of the expense and brittleness of molybdenum and tungsten refractory metals used in hot zone construction, most MIM parts manufacturers prefer to carry out the first stage debinding in separate low temperature ovens, and use the vacuum sintering furnaces for second stage polymer debinding and final sintering steps. Even with the advent of solvent debinding, the long debind cycle times make it wise to carry this process out in lower cost units instead of tying up valuable time in expensive sintering furnaces.

This version of sweepgas processing has a number of design improvements specific for use with MIM feedstocks: tight partial pressure control and consistent gas flow with sound retort design allows the entire load to view the same series of conditions as a function of time. This results in consistent microstructures and repeatable carbon control. To accomplish this the gas-plenum retort has rows of perforations allowing even gas flow across all the work trays (Figure 11).

Unlike traditional sweepgas for hardmetals, which is designed to operate at a maximum partial pressure from 0-10 torr, MIM sweepgas (using either inert gas or hydrogen process gas) is designed to operate from 10-500 torr and higher. Instead of flowing the sweepgas into the chamber and letting it diffuse through the hot zone into the retort, the MIM gas circuit plumbs gas to both the outside of the chamber, and the gas plenum retort.

The retort gas flows over the trays to sweep away binder offgassing, while the chamber 'guard' gas ensures minimal binder condensation on the cold chamber walls. The binder-laden gas is pumped out the bottom of the retort through the pumpout tube, while a closed loop controller maintains consistent vacuum levels during debinding.

This last fact is critical as large swings in vacuum level during debinding can have catastrophic consequences. Excessive sweepgas flows during polymer removal can also cause problems as the gas can blow apart the fragile parts, spraying metal powder all over the inside the hot zone, where it is later sintered.

A relatively new sintering atmosphere desired by the MIM industry is a partial pressure of hydrogen gas. While this is in the flammable range of hydrogen (from 15 torr – 75% hydrogen), the environment offers MIM companies the following advantages:

- Low partial pressures of a reducing environment tend to remove an oxide phase much faster than at positive pressures.
- Less hydrogen gas is used at partial pressures than at positive pressures.
- Partial pressures provide a more thorough 'sweeping' action to remove carbonaceous binder byproducts and remove the offgassing out of the hot zone, instead of relying on positive pressure gases to purge it out.
- At partial pressures, any hydrogen that reacts with oxygen to form water vapour would be removed by the vacuum pumping system. There is also less hydrogen present to react with graphite hot zones (forming methane gas, which lessens hot zone life, and can alter the carbon content of the parts).

For systems designed to operate in partial pressures of hydrogen, the following safety features are required:

- Programmable 'automatic' leak check cycle.
- Pneumatic clamps on front and rear doors.
- Inert gas purge connected to pump gas ballast, inlet and exhaust ports.
- Double O-rings on door flanges and binder pots with pumpable grooves.

Depending on the customer's process requirements and feedstock design, a variety of wax and polymer condensation strategies have been developed.

The most popular is a 'T/P' (or Trap over Pot) design. It is a multi-stage wax/polymer condenser with removable media baskets, filled with high surface area pall rings and stainless steel wool, connected to the debind manifold which is heat traced and insulated to the chamber. The trap body can be outfitted with heater bands and an insulation jacket to allow the canister to 'self-strip' by heating up to the melting point of the wax/polymer allowing it to melt and flow downwards into the knockout pot underneath, greatly simplifying trap cleaning.

Depending upon the binder system used, the 'T/P' condenser can also be water traced/jacketed to maximize condensation of wax vapours for efficient trapping.
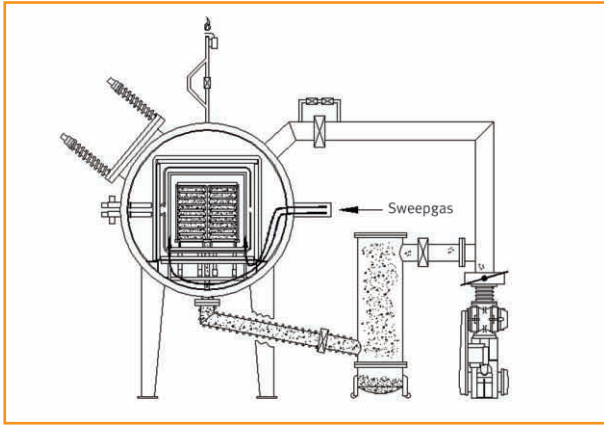
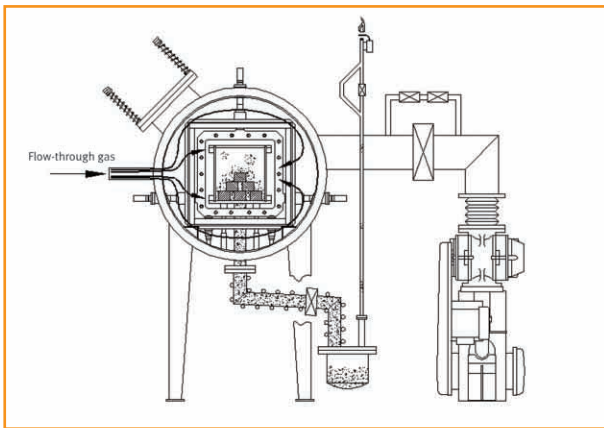**Figure 12:** MIM sweepgas process for debinding MIM parts.

Figure 13: Positive pressure gas flowthrough system for debinding where the use of vacuum is inappropriate.

Positive pressure flowthrough debinding

Some binders do not lend themselves to vacuum debinding. The materials have high vapour pressures making the use of vacuum ineffective, or they decompose into tarry, sticky phases that would destroy vacuum pumping systems in a short time period. Here, a positive pressure environment is desirable (Figures 13 and 14).

With this design, a flow of inert gas or hydrogen process gas is used to purge the chamber of binder buildup and process related offgassing as the hot zone is gently heated up. Gas flows up to 25 times the hot zone volume per hour can be required for effective binder removal. The flowthrough gas enters the retort and sweeps across the parts carrying the binder vapours out the bottom through a pumpout tube to the debind manifold which is heat traced and insulated to prevent binder condensation. The gases enter an empty binder pot underneath the chamber where a majority of the binder condenses, and the balance flows out an exhaust tower mounted off the pot through a propane/natural gas operated burnoff. This manifolding is also heat traced and insulated.

When using hydrogen process gas (common for polyethylene glycol [PEG] binder systems), the hydrogen exhaust tower is mounted off the binder pot instead of the top of the chamber. While this design is effective for small amounts of binder, it is not designed for quantities over 4-5%. The propane tower will combust most gases, but

excessive particulate will clog the orifice or pass through the flame tower uncombusted. The binder will then cool in the upper air stream, condense, and rain back down on the furnace chamber.

To combat this problem a variation of this system has been developed for non-oxide ceramic sintering. Gas is flowed into the retort to entrain binder/process offgassing and direct it out the pumpout tube, while gas flow into the chamber is used to prevent process gas leakage out of the retort where it can attack the graphite hot zone element/insulation, and minimize binder condensation on the cool chamber walls.

The binder pot and tower are replaced with an inert gas purged, full sized thermal oxidizer for VOC management and adherence to state and federal regulations.

The design challenge is how to maintain a vacuum seal in an environment with sticky, corrosive binders. Most high temperature valve designs suffer corrosion or thermal damage to the O-ring seals. The answer was a custom-designed 'Griff' valve (Figure 15), which was developed to seal the chamber during vacuum operation, plunge the orifice on an intermittent stroke to ensure minimal clogging, and is used to control the rate of exhaust of positive pressure flowthrough gases.

With this design, large binder contents and tarry, sticky binders can be handled with the proper maintenance.

The primary advantage of these positive pressure systems over vacuum debinding is the ability to 'bathe' the part in warm gas which provides more uniform heating than radiation heating in a vacuum environment due to the thermal transfer from gas conduction and convection.

Continuous furnace debinding systems

Lubricant removal in hot wall pusher furnaces and belt furnaces has been performed for years in the PM industry. The lubricants are removed in a positive pressure environment, either of inert gas or a mixture of inert gas and hydrogen, with great success. Today's lubricants are designed to burn off cleanly with little leftover residue.

This is not the case with non-oxide ceramics, tungsten carbide hardmetals or MIM parts. More care must be taken during binder removal to ensure the desired residual carbon content is achieved.

Centorr/Vacuum Industries manufactures a cold wall belt furnace rated for 2000 °C in either metal or graphite

Figure 14: Centorr/Vacuum Industries' positive pressure hydrgen gas debinding system.
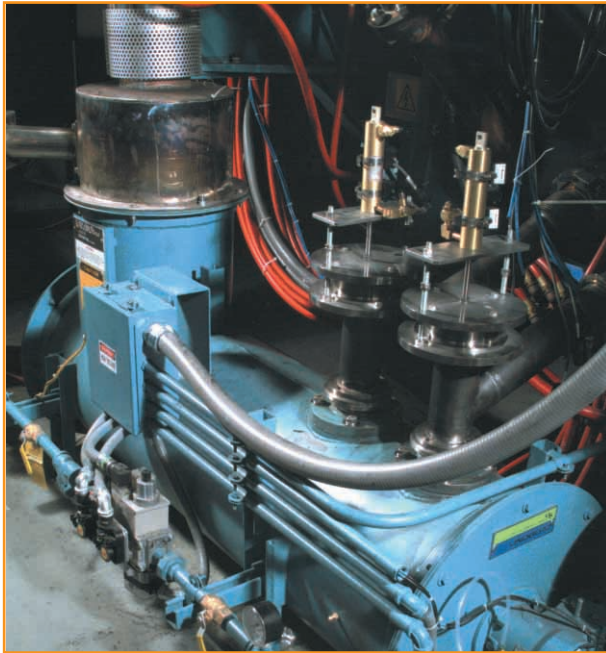
Figure 15: 'Griff' valves on debind manifold with incinerator.

hot zones. The company also manufactures a cold wall pusher furnace rated for 2300 °C operation with an inline debinding zone. Inert gas is flowed through the back end of the furnace where it cools the parts exiting the sintering zone. The gas sweeps process offgassing into the debind zone where the inert gas forces the products of combustion to exit out of ports in the bottom of the pusher track to a floor mounted incinerator. All debind manifolding is insulated to minimize condensation and plugging.

Load locks are included on both the entrance and exit zones to prevent air infiltration, which could affect product quality and insulation integrity. The graphite pusher furnace can be designed as a vacuum or inert gas atmosphere furnace with vacuum debinding or positive pressure debinding.

Sintering

The topic of sintering metals, hardmetals and ceramics could fill several volumes. The information here is a brief description of things to keep in mind when selecting a batch or continuous sintering furnace for a specific process.

A typical hardmetal sintering furnace has a graphite hot zone, consisting of graphite felt or rigid board insulation, a four-sided heating element and a single zone of control.
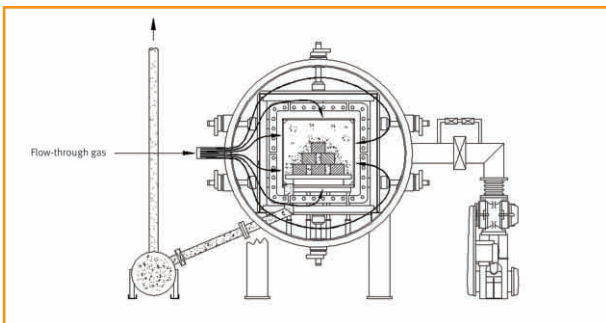

Figure 16: Positive pressure gas flowthrough system with incinerator.

This is adequate for temperature uniformities of ±5-10 °C inside the retort at 1600 °C maximum temperatures.

Newer MIM debind and sintering furnaces are very different. Tight sintering windows dominate and temperature uniformity under ±5 °C is necessary. This requires the use of multiple zones of control and precise tuning of the PID loops.

Graphite-lined MIM furnaces will have two or three zones of control (front, middle and rear or top/bottom control) and sometimes six-sided heating for larger hot zones with heating elements on the doors.

Metal hot zone designs almost never use heating elements on the doors due to the frequent opening/closing and the effect on the durability of crystallized moly/tungsten heating elements. Here six independent zones of control are used (three top, three bottom), and uniformities of ±3-5 °C are attainable in vacuum or a positive pressure of hydrogen gas.

The smaller work cross-sections in a continuous furnace offer minimal thermal inertia compared to batch furnaces. The heat-up rates and cool-down rates in large load batch furnaces often limit process capabilities and lengthen cycle times. Cold wall continuous furnaces can be heated up to maximum temperature and cooled below 150 °C in under 3-4 hours. Continuous furnaces can offer a large cycle time reduction translating to excellent throughput.

Company brief

Centorr/Vacuum Industries is a manufacturer of high temperature vacuum/controlled atmosphere furnaces with an installed base of over 6000 units worldwide. The company's furnace offering ranges from large commercial and production units with hot zones over 3m x 3m, to smaller lab and R&D furnaces for use at temperatures over 3000 °C. Centorr/Vacuum Industries is based in Nashua, NH, USA, with a fully staffed aftermarket field service group, and an Applied Technology Center offering R&D support and toll production services.

Further reading

(1) S.W. Kennedy and C.W.P. Finn, 'Metal Injection Molded Part Debinding and Sintering in Vacuum Furnaces', *Powder Metallurgy Science & Technology*, vol. 1, no. 3, (1990), p. 37.

(2) R.M. German, 'Variations in the Essential Powder Injection Molding Processes', Gorham Advanced Materials Institute, Monterrey, CA, March 1989.

(3) F. Andersen, 'Performance Evaluation of Gas Atmosphere Delubing and Sintering in Sintervac® Furnaces', *Metal Powder Report*, vol. 39, no. 2, February 1984.

(4) C.W.P. Finn, 'Vacuum Binder Removal and Collection', *Int J. Powder Metal.*, vol 27, no. 2, (1991).

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