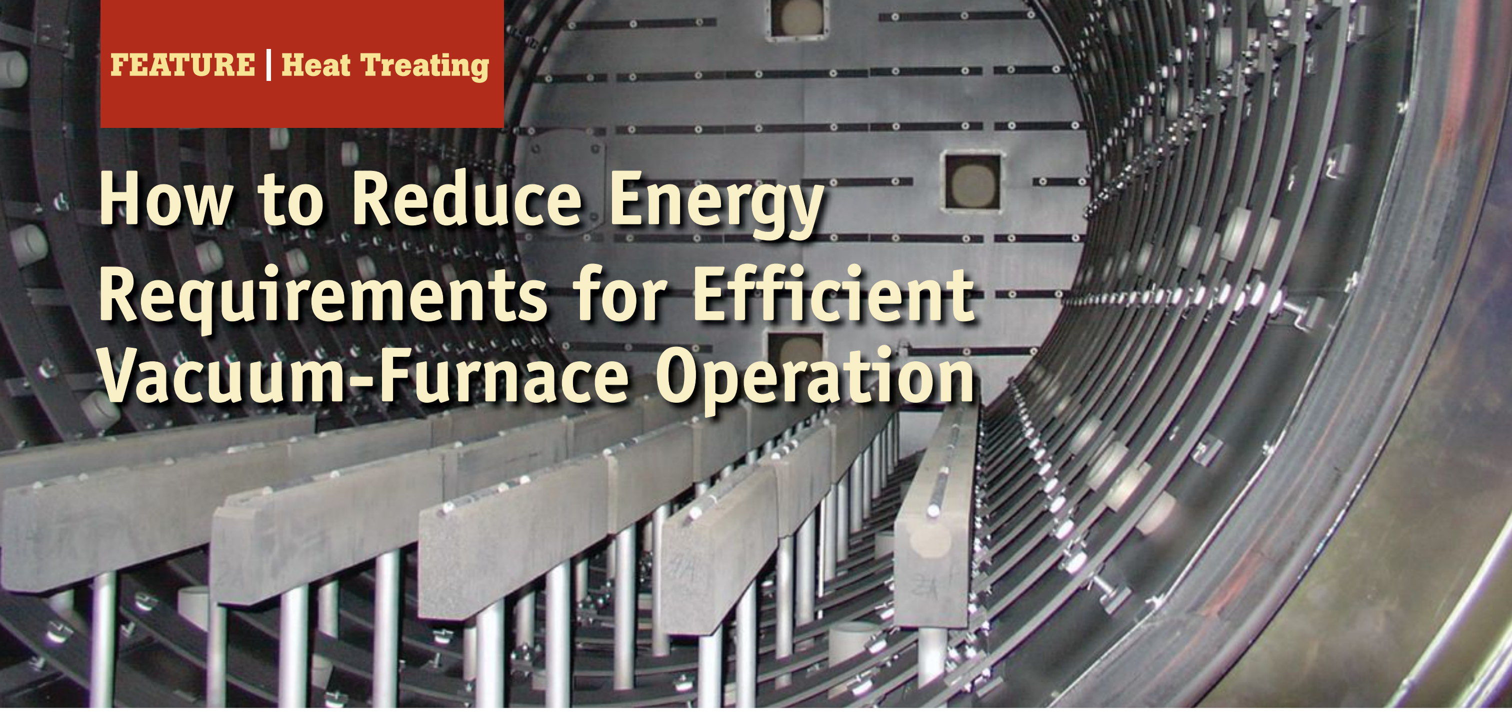

How to Reduce Energy Requirements for Efficient Vacuum-Furnace Operation

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Of the many papers written on methods of reducing vacuum-furnace operating energy requirements, most tend to highlight one specific furnace area. This article will outline various methods of reducing energy requirements of several furnace functions.

The vacuum-furnace functions discussed will include:

- Hot-zone configuration and types of insulation used
- Variable-frequency drives (VFD) on vacuum pumps and gas cooling motors
- Diffusion-pump heaters
- Supporting water systems

Controlling and Minimizing Hot-Zone Energy Losses

Vacuum-furnace hot zones historically have incorporated many different designs, including: all-metal designs utilizing a stack of thin metallic shields; ceramic-fiber designs using combinations of fiber board or blankets; and the most modern design, hot zones utilizing graphite insulation in the form of sheet, felt or board. As 80-90% of production vacuum furnaces today use graphite felt behind a graphite-foil hot face, our studies will consider ways of improving graphite-felt designs.

Based on accumulated data and prior testing, we have established a power-loss ratio for various graphite-felt thicknesses. This data is plotted in Figure 1 with 2 inches of graphite felt as the base, and losses are illustrated relative to that thickness.

Although Figure 1 illustrates the advantage of adding layers of felt to the base 2-inch thickness, it reflects diminishing returns for each additional layer. Cost of the extra layer versus expected resulting savings must be assessed and is contingent on the cycles to be processed. Long cycles with long holding times at elevated temperatures benefit most from an additional layer of felt.

In analyzing the energy savings expected with an added layer of graphite felt, we must assume certain operating conditions. An average cycle might look like Figure 2. Using this typical cycle with an average load weight of 1,000 pounds and 520 cycles per year, we can continue our analysis.

Based on actual tests of a typical furnace with a 36-inch-wide x 36-inch-high x 48-inch-deep hot zone insulated by four layers of ½-inch graphite felt with a graphite hot face supported in a stainless steel structure, using applicable heat-transfer calculations we can summarize energy requirements as shown in Fig. 3. From this chart, we can now analyze the energy loss and how it can be affected by an additional layer or two of felt insulation.

Using our loss-ratio chart, we can project that improvement will be

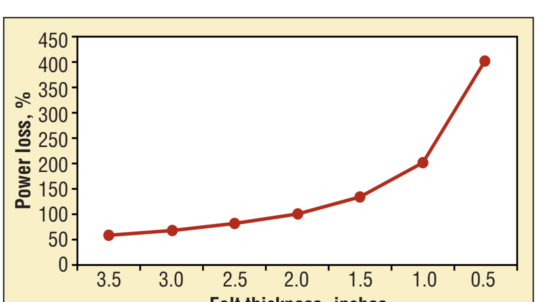

Fig. 1. Power-loss ratio

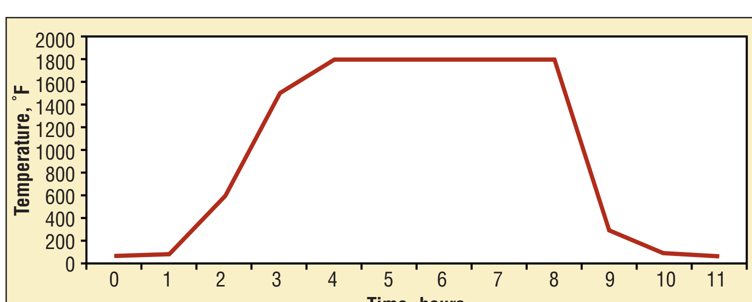

Fig. 2. Cycle temperature

Fig. 3. Energy requirements for a "typical" furnace

Cycle component	Energy required
Heat load to 1800°F	
Load heating energy	60 kWh
Hot zone heating energy	83 kWh
Loss energy	47 kWh
Total heating energy	190 kWh
Energy to hold at 1800°F – 4 hours	
Loss energy per hour hold	63 kWh
Total holding energy	252 kWh

Fig. 4. Energy requirements and cost

Energy losses	Total cycle kWh losses	Cost/year
Four-layer graphite felt insulation	299 kWh	$17,103.00
Five-layer graphite felt insulation	254 kWh	$14,528.00

Fig. 5. Energy savings based on 520 cycles per year

Pump operation without VFD/cycle	Pump operation with VFD/cycle	Energy savings/ cycle	Energy savings/ year	Savings/year based on $0.11/kWh
112 kWh	28 kWh	84 kWh	43,680 kWh	$ 4,804.80

Fig. 6. Annual energy savings using a VFD

Total motor energy without VFD/cycle	Total motor energy with VFD/cycle	Savings/cycle	Savings/year (510 cycles)	Savings/year at $0.11/kWh
111.9 kWh	54.3 kWh	57.6 kWh	29,376 kWh	$ 3,231.36

approximately 17% for one added layer of insulation. There are other losses to be considered, however, such as nozzle openings and hearth penetrations, leading to a more conservative savings estimate of 15%.

Based on the above, we can now project the following expected energy savings with the added layer of felt insulation and the cost per year at a rate of $0.11/kWh (Fig. 4).

For this furnace, if the initial construction cost for an additional layer of graphite is approximately $3,000, payback over the life of the hot zone (five to seven years) is well worth the investment. Again, however, each individual operation must analyze its specific cycles to determine optimum hot-zone configuration.

The above represents only one simple way to reduce hot-zone power losses. Other methods under study show significantly better results and will be announced to the industry in the near future.

Variable-Frequency Drives on Vacuum Pumps and Gas Cooling Motors

Vacuum Pumps

A vacuum furnace uses several large motors on the pumping and gas cooling systems. As full output of these motors is not required during certain phases of a typical heat-treating cycle, the use of variable-speed or variable-frequency drives could result in considerable power savings over time.

A variable-frequency drive (VFD) system controls the rotational speed of an alternating current (AC) electric motor by controlling the frequency of the electric power supplied to the motor. AC motor-driven applications not requiring full speed can save energy by controlling the motor with a variable-speed drive. Energy cost savings with these systems can be significant, often paying for the cost of the VFD within a matter of months. In variable-torque applications, such as vacuum pumps and gas cooling blower motors, the torque required varies roughly with the square of the speed, and the horsepower required varies roughly with the cube of the speed, resulting in a large reduction of horsepower for even a small reduction in speed. A motor will consume only 25% as much power at 63% speed as it will at 100% speed.

Most vacuum systems include a vacuum blower pump ahead of the mechanical pump. This pump is critical when pumping down from the 50 torr range to 50-60 microns, where it should be operating at full speed and capacity. During other phases of the pumping cycle, however, a much lower pumping speed is appropriate. Considerable energy savings can thus be accomplished with a VFD.

When the mechanical pump initiates vacuum pump-down, the vacuum blower impedes the throughput because it is between the vacuum chamber and the mechanical pump. If the blower is off, its lobes will restrict the pumping of the mechanical pump. By rotating the blower pump slowly at a higher pressure while controlling overload concerns, vacuum-pumping cycle time is reduced prior to initiating full speed to the blower. Also, when the diffusion pump enters the cycle at 50-60 microns, the blower can again be reduced to slow rotation as the mechanical pump backs the diffusion pump. A typical vacuum blower pump 15-HP motor uses approximately 11.2 kW at full speed. When idling the blower at 50% speed or slower, we reduce power usage to approximately 2.8 kW, which could represent a significant long-term savings even after the initial cost of the VFD. Running the blower at reduced speeds will also extend the life of the blower and decrease maintenance requirements, resulting in additional savings.

Energy savings possible with a VFD on the blower pump motor can be summarized with the following projection. If we refer to Figure 2, representing about a 10-hour cycle, the full speed of the blower pump is required only for approximately one hour of that cycle. Without the VFD, it would be operating at full speed for approximately nine hours of the cycle. Figure 5 demonstrates the energy savings based on 520 cycles per year.

A VFD for this size motor would cost approximately $3,500, which would represent a payback after the first eight to nine months. There are additional savings, as previously stated, of extended blower life and reduced maintenance.

Although there are times when the mechanical pump could be reduced in speed during the cycle, the possibility of savings is minimal because the mechanical pump

Fig. 7. Energy comparison

Nominal DP heater energy/cycle	Reduced DP heater energy/cycle	Energy savings/ cycle	Energy savings/ year (520 cycles)	Savings/year at $0.11/kWh
120 kWh	72 kWh	48 kWh	24,960 kWh	$2,745.60

Fig. 8. Savings for a typical cycle for an average load (Fig. 2)

Cycle segment	KWh without VFD	KWh with VFD	Difference
Hours 0-4	44.4 kWh	11.1 kWh	33.3 kWh
Hours 4-8	44.4 kWh	44.4 kWh	0
Hours 8-10	22.2 kWh	22.2 kWh	0
Hours 10-12	22.2 kWh	0.0 kWh	22.2
Total/Cycle	133.2 kWh	77.7 kWh	55.5 kWh/cycle

backs the blower and the diffusion pump after it has provided the initial pump-down. Therefore, we do not recommend a VFD for the mechanical pump.

Gas Cooling Motors

A VFD on a gas cooling-system motor not only provides energy savings but also enhances cooling performance.

Most furnaces are designed with a system that produces cooling using gases such as nitrogen or argon at 2-bar pressure. This requires designing the recirculating fan and motor size for one of the gases and accepting whatever the performance of the other gas happens to be. This lack of adaptability is acceptable to some operations but not to the modern heat treater.

By introducing a VFD on the blower motor and designing the system for maximum performance of the heavier gas required, the system can provide optimum performance for other gases. Having the capability of reducing motor speed during the cooling cycle will also reduce total operating costs, especially on larger cooling motors.

Most cycles require fast cooling in the initial phase – from final soaking temperature to some lower temperature. When the lower temperature is reached, the blower motor can be reduced in speed to 50-60% power, saving considerable energy. By reducing the speed, factors such as reduced heat of compression also come into play, which actually speed up cooling at lower temperatures.

Standard furnaces normally incorporate

either a 50-HP (37.3-kW) or a 100-HP (74.6-kW) motor. By reducing the speed to 50%, the kW requirement on these motors is reduced to approximately 8.5 kW or 17 kW. Extending these numbers over the cooling period represents significant energy savings and provides for extended motor life. Other furnaces incorporating 10- and 20-bar cooling systems use motors that are rated for 300 HP (223.8 kW), making a VFD system useful for greatly reducing energy consumption.

We can project an annual energy savings when using a VFD on the gas cooling-system motor by again referring to Figure 2 and assuming the 50-HP motor typical of most standard systems. Without the VFD, the motor would operate for approximately three hours. With the VFD, we would have one hour at full speed and two hours at 50% speed. Figure 6 projects this information.

The cost of a VFD for this size motor is approximately $5,200. The payback takes somewhat longer, but flexibility regarding using different gases to optimize performance and reduce wear and tear on the gas cooling motor makes this investment very attractive.

Minimizing Diffusion-Pump Energy Consumption

A diffusion pump incorporated into the vacuum system to achieve low-vacuum ranges is only active during initial pump-down from cross-over (50-60 microns) to low-vacuum (10^{-4} or 10^{-5} torr) range and for recovery of vacuum when product outgassing reaches a pre-set level. At other times, the diffusion pump can operate at lower power requirements. The heaters for the diffusion pump will draw power ranging from 8 kW for a 16-inch pump to 24 kW for a 35-inch pump at full power.

Utilizing an SCR power controller in conjunction with an integrated control system, we can reduce power consumption by approximately 50%. This energy-saving feature can be used after the furnace has achieved desired vacuum, when the furnace is quenching and when the furnace is being loaded or unloaded, offering significant power savings and greatly extending the life of the diffusion-pump heaters.

Figure 2 illustrates the typical cycle we have been using for all our studies. This is approximately a 10-hour cycle where the diffusion pump is only required to operate at full power for about two hours. If we assume this furnace has a 20-inch diffusion pump with 12 kW of power required for full operation and 6 kW for idling, and operating 520 cycles per year, we can create the energy comparison shown in Figure 7.

The control system's initial cost is approximately $1,450, illustrating that this investment is quickly recovered in the first year and provides continuing savings and longer heater life for several years.

VFDs and Temperature-Controlling Logic on Cooling-Water System

All vacuum furnaces require some type of supporting water-cooling system for various furnace components and for the gas cooling heat exchanger. Most installations today are either an open recirculating-type utilizing an evaporative cooling tower or a closed recirculating-type utilizing a forced-air-cooled heat-exchanger system.

All systems incorporate a pump or pumps to recirculate water from the supporting reservoir back to the furnace system. These pumps normally operate at full capacity during furnace operation. With a VFD on the pump motors (typically 15-25 HP), we can provide significant energy savings for a given installation. Control logic can be added to monitor varying water temperature and to reduce pumping-motor speed when appropriate during the process.

When the recirculating water is below 70°F, the motor can essentially be turned off. When the recirculating water temperature is 70-79°F, the pumps can be operated at 25% power, and when the temperature is 80-89°F, the motors can be operated at 66% power. Above 89°F, the pumps will operate at 100% power.

As illustrated, there is an excellent opportunity to control and minimize pump-motor power consumption, and each installation must be evaluated for possible energy savings using a VFD on these devices. Based on prior studies, initial cost is easily returned by savings within the first 12-18 months.

For a typical water system, including only one 15-HP recirculating pump motor requiring full speed at certain times, we can project the savings shown in Figure 8, based on our typical cycle for an average load as shown in Fig. 2.

If we extend this out to 520 cycles/year with power at $0.11/kWh, the resulting savings are approximately $3,146 per year. With the VFD and control logic costing approximately $4,500, the original cost is quickly recovered and provides for extended motor life.

Conclusions

We have illustrated several ways of reducing furnace energy costs. With the continually increasing costs of electric power, our industry must invest time, effort and ingenuity to find additional ways of improving on our designs to minimize these costs and extend the life of expensive equipment. **IH**

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