The primary purpose of a furnace is to provide heat to the product or load, so basic knowledge of desired furnace heat-transfer characteristics helps in understanding why and how pulse firing can be beneficial.

**Furnace Heat Transfer**
Thermal efficiency is a measure of getting heat from the burner to the load. It is important to isolate factors that are not related to the burner firing method (pulse vs. amplitude modulation) when making comparisons. The Sankey diagram in Figure 1 highlights ways to increase efficiency that are not related to the burner firing method, such as:

- Reducing the exhaust losses with heat exchangers to preheat the combustion air of the burner
- Reducing wall losses by increasing and maintaining wall insulation
- Reducing opening losses by maintaining door seals and furnace pressure control
- Reducing heat storage by installing low thermal-mass insulation in batch furnaces where the temperature cycles regularly

The transfer of energy from the flame and hot combustion gases to the load depends on the difference in temperature and the barriers that impede the transfer. So, efficiency gains that are related to the burner firing method correlate to excess air and velocity.

**Excess Air**
Excess air is the amount of air above what is required for complete combustion of the fuel. It can come from the burner, openings in the furnace or it is purposefully injected to stir the environment to get uniform temperature throughout the furnace. Excess air acts as an additional heat load because it must also be heated. Therefore, more excess air requires more fuel. Excess air reduces the temperature of the flame and products of combustion, and thus, the heat-transfer rate is also lowered.

**Velocity**
Velocity is the speed of the products of combustion ejected from the outlet of the burner. Faster hot combustion gases deliver more heated mass across the load surfaces. The higher mass flow carries more heat across the entire distance of the load before the stream cools, and as a result, the temperature differential and heat-transfer rate are increased. In some designs, the high velocity scrubs the load surface and reduces the thickness of the layer of dead air stuck by surface friction. This dead layer acts as an insulating barrier. Therefore, reducing its thickness improves heat transfer.

Another advantage of higher velocity is stirring of the furnace atmosphere to level the temperature throughout the furnace volume. This effect is demonstrated in Figure 2, where the high-velocity stream draws in surrounding air. The entrainment can be 10 times the volume for burner outlet velocity at 500 feet per second (340 mph or 150 meters per second).

Production quality requires all parts of the load, no matter where they are located inside the furnace, to reach and stay at the desired temperature. Good profits come from quick production throughput by rapidly heating the load to its desired temperature. Therefore, uniformity and high heat-transfer rates are important furnace characteristics.
The primary function of a combustion control system is to vary the heat input to a process in order to sustain the desired temperature. The heat input is typically adjusted by two methods: amplitude or frequency modulation.

Amplitude-Modulating Control
With the amplitude-modulating control method, the burners are regulated between high and low fire in a continuously variable manner, as depicted in Fig. 3. Normally, a butterfly valve or some type of variable flow control adjusts the amount of fuel and air delivered to the burner, achieving a firing rate (Btu/hr or kW) that maintains the temperature of the load.

This traditional method requires burners with good turndown (high vs. low firing rate) to meet the varying heat input of most applications. For large furnaces, a group of burners are fired and controlled together. This approach offers good control and flexibility for a reasonable price when burners with sufficient turndown are used.

Frequency-Modulating (Pulse) Control
In a frequency-modulating control method (pulse firing), the burners are switched between two states, and the cycling of the burners controls the heat input to the process. The burners are fired at high fire for a certain time and then cycled to either low fire (high-low control) or turned off (on-off control). This cycle is repeated quite frequently, and in some designs it is six seconds. Faster cycle rates improve temperature uniformity at the cost of reduced equipment lifetime. The minimum on and off times are dependent on the response times and delays of the control devices, such as the flame safeguard, valve actuation and burner ignition.

The heat-input demand determines the duty cycle, which is the length of time the burner is at high fire and then at low fire (or off). Figure 4 shows the timing of four burners – b1 through b4 – fired in a pulse sequence at three different heat-input rates. Pulse firing by the on-off control method allows the use of burners with limited turndown in systems requiring a larger turndown than is possible with amplitude-modulating control. With individual control valves at each burner, it is possible to cycle burners independently for the greatest control flexibility. However, pulse firing does come at a price and an increase in system complexity.

A generalized comparison of modulation methods is presented in Table 1. These ratings are subject to debate, however, because specific features and control components can be added to any system to improve deficiencies.

Safety and Codes
There are two predominant application standards that must be considered when applying pulse firing to furnaces. The U.S. follows NFPA 86 and the E.U. follows EN746-2. Other countries typically adopt these or develop similar standards. The standards should be examined prior to making design, purchase and operational decisions.

The condition for concern with pulse firing in the on-off mode is when the furnace is below 1400°F (750°C) and the burners are off. During the off time, a valve failure could lead to a collection of unburned fuel. When all burners in a zone turn off, the standards normally require a purge before any burners can come back on. The European standard has specific exceptions to this purge for the case
of pulse-firing equipment. The American standard limits the off time based on a calculation of a defined gas-valve leakage rate. Additionally, NFPA requires enhanced maintenance schedules and monitoring of usage.

There is another concern with the cycle timings. The minimum on time is determined by the flame safeguard. It may have a start-up delay time before it energizes the ignition and gas-valve outputs. The on time must be longer than the trial for ignition time (first safety time) plus the flame failure-response time. Otherwise, each subsequent attempt to light a burner that does not produce a flame will allow discreet volumes of unburned fuel to collect in the furnace without achieving a flame-safeguard alarm and a lockout condition. Eventually, these pockets of unburned fuel could collect and mix with air in the furnace and cause an explosion.

**Equipment Selection Considerations**

At the heart of a pulse-firing system are the valves on the air and gas lines to each burner. The valves selected need to be designed specifically for pulse-firing applications. At a frequency of 10 cycles per minute, 12 hours per day, five days per week, the valves will be subjected to 36,000 cycles per week or 1.8 million cycles per year. Standard solenoid valves will last only about six months in these conditions.

These high cycle rates also apply to the control devices and their contact ratings. The lifetime of a contact depends on the number of operations, the current flow and the type of load. Unfortunately, loads such as solenoid valves and ignition transformers are highly inductive and create sparks on the contacts. These sparks erode the metal in the contacts and shorten their life. Contact life can be increased by installing arc suppressors.

To ensure that air is flowing through the burner at the time of ignition, the air valve needs to be mounted close to the burner air inlet. It is also critical to install a ratio regulator at each burner to minimize variations of the air-gas ratio.

It is important that the main gas-supply regulator is properly sized. An excessive variation of the inlet pressure into the ratio regulator can affect ignition reliability.

A number of specialized controllers dedicated for a specific pulse configuration are available. These controllers offer the advantages of a compact design, requiring minimum programming by the user.

Many pulse-fired burner-management systems are built with a programmable logic controller (PLC). These systems can offer more functionality and customization than the specialized controllers. A single PLC with enough processing power can control the pulse sequencing and also all other furnace functions. If the PLC is a brand commonly used throughout the plant, then the maintenance personnel will be trained and familiar with it. This makes set up and troubleshooting of this equipment much easier.

With either a specialized controller or a PLC, adjustments should be made to reduce the accumulated number of cycles while maintaining an acceptable stability of the process temperature.

**Conclusion**

In specific applications, significant advantages can be achieved when applying pulse-firing technology correctly. As with any technology, a solid understanding of the basic concepts helps achieve successful implementation. This article introduces some of these concepts. It should be followed in conjunction with a strong working relationship between the end user and the equipment supplier.

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**Table 1. Comparison of pulse modes and amplitude modulation**

<table>
<thead>
<tr>
<th>Feature</th>
<th>On-off pulse</th>
<th>High-low pulse</th>
<th>Amplitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turndown</td>
<td>Best</td>
<td>Better, requires precision settings</td>
<td>Good, depends on burners per zone</td>
</tr>
<tr>
<td>Emissions</td>
<td>Best</td>
<td>Better, depends on burner low fire characteristics</td>
<td>Good</td>
</tr>
<tr>
<td>Safety</td>
<td>Good, must determine codes and deal with hazard when all burners are off</td>
<td>Better</td>
<td>Best, traditional systems with user familiarity</td>
</tr>
<tr>
<td>Life &amp; maintenance</td>
<td>Good, wear on all components for cycle rate</td>
<td>Better, fewer components cycling</td>
<td>Best, slower rates of change</td>
</tr>
<tr>
<td>Reliability</td>
<td>Good, more chances of failed ignition</td>
<td>Better</td>
<td>Best</td>
</tr>
<tr>
<td>Cost</td>
<td>High</td>
<td>High</td>
<td>Low</td>
</tr>
</tbody>
</table>

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For more information: Dan Curry, product development manager – controls, Eclipse, Inc., 1665 Elmwood Rd., Rockford, IL 61103; tel: 815-637-7265; e-mail: dcurry@eclipsenet.com; web: www.eclipsenet.com