Advanced Oxy-Fuel Burners and Controls Improve Fuel Savings and Uniform Heating

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Figure 5. DOC installed in a "box" reheat furnace

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As performance requirements for forged parts increase, so also do the technologies used to produce them. Reheat furnaces are one example of equipment that must meet tighter performance specifications.

An advanced oxy-fuel technology called Dilute Oxygen Combustion (DOC) substantially improves temperature uniformity and reduces NOx, carbon emissions and natural gas consumption relative to air-fuel burners in reheat furnaces. These pulse-fired oxy-fuel burners have demonstrated a temperature uniformity of less than ±15°F, with NOx emissions of 0.01 pounds/million Btu or less, while reducing fuel consumption by as much as 70%.

Earlier versions of this technology were developed in the late 1980s and refined through the 1990s. Commercial combustion systems of these advanced designs were developed and implemented under a DOE project in the late 1990s. To date, these advanced oxy-fuel combustion systems have been installed on continuous steel reheat furnaces, batch reheat furnaces, batch metal melting furnaces, ladle preheaters and glass-making furnaces.

Dilute Oxygen Combustion Concept

In DOC, the fuel gas and oxygen are injected separately via high-velocity jets, creating rapid mixing of the fuel and oxidant with hot furnace gases (Figure 1). This mixing and dilution produces a thermally uniform heat release with low peak flame temperatures, resulting in more even temperature distribution throughout the furnace. The low flame temperatures are key to inhibiting the production of thermal NOx. Often, when observed in a hot reheat furnace, the DOC flames are diffuse enough as to be invisible to the human eye (Figure 2).

The J/L Burner

The specific burner utilized, called the J/L Burner, incorporates DOC technology in a "packaged" assembly. In a typical arrangement,

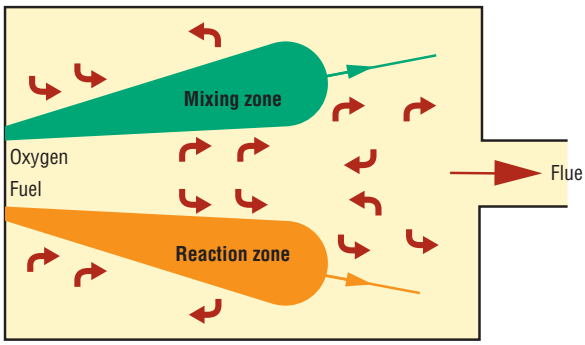
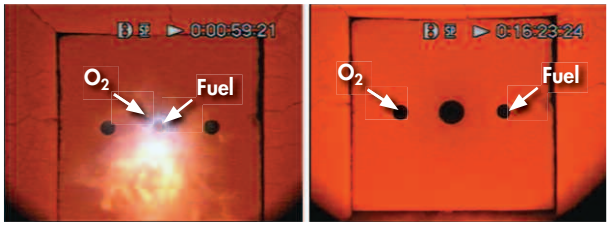


Figure 1. The DOC concept

- Separate fuel and oxygen injection at high velocity
- Rapid dilution of fuel and oxygen with furnace gases
- Diffuse flame results in very uniform heating
- Low peak flame temperature minimizes NOx production



Typical oxy-fuel burner, high flame temperature, point source heating

Dilute oxygen combustion, low flame temperature, dilute heating

Figure 2. DOC technology produces essentially "flameless" combustion.

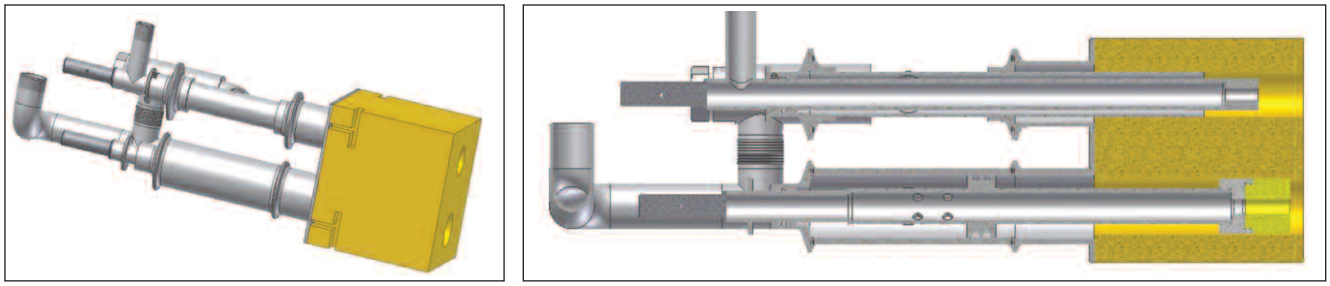


Figure 3. The J/L Burner used for DOC

several burners will be mounted on the sidewalls of the furnace. The burners/lances are compactly unitized within a refractory block requiring a single furnace penetration per burner (Figure 3).

One key aspect of the burner is that the nozzles are field replaceable so that gas injection velocities can be tailored to achieve a furnace's specific needs. This improves burner versatility and allows parameters such as luminosity, burner momentum, flame intensity, flame length and heat-flux profile to be controlled for each application. The burner also features flame supervision, automatic spark ignition and air cooling for low maintenance requirements.

The J/L Burner has two main components: the J-Burner portion and the lance portion. The J-Burner consists of a fuel-injection assembly retained within a concentric oxygen tube. Its design makes use of a patented technology that permits the J-Burner to be recessed within the burner refractory block for protection from heat and without risk of damage from combustion within the recess cavity.

The lance portion of the burner injects oxygen whenever the furnace is above the fuel auto-ignition temperature. It is separated from the J-Burner by several inches in order to entrain furnace gases and prevent the mixing of oxygen and fuel close to the burner, thereby delaying combustion. This allows the oxygen to become "diluted" with the furnace gases, yielding a much lower flame temperature. Since combustion takes place throughout the furnace chamber instead of directly at the burner, a more diffuse flame is produced, resulting in more even energy distribution throughout the furnace.

Valve Skid, Burner Manifolds and Controls

A code-compliant oxy-fuel combustion system appropriate for employing DOC technology includes a main valve rack for pressure regulation and main shutdown control, burner manifolds for gas control to each burner and the electrical control panel for overall process control. For pulse firing, each burner manifold includes long-life solenoid valves. Systems come complete with a programmable logic controller (PLC) and a local human machine interface (HMI). With this system, the operator has the capability and option of employing centralized monitoring of furnace parameters through an available communication network.

Pulse Firing

In pulse-firing technology, burners alternate between maximum and minimum firing rates rather than modulating to intermediate rates. To control furnace temperature, the timing of the firing cycles is adjusted depending on the required heat input. Pulse-firing control can be thought of as frequency modulation rather than amplitude modulation. In a typical cycle, the burner might fire at maximum rate for five seconds and minimum rate for five seconds for a 50% energy input to the furnace.

In its pulse-fired mode, the J/L Burner produces the same heating characteristics and momentum each time the burner fires. This leads to extremely uniform heating throughout the furnace. Combustion efficiency is maximized because excess air is not required to maintain burner momentum at low firing rates.

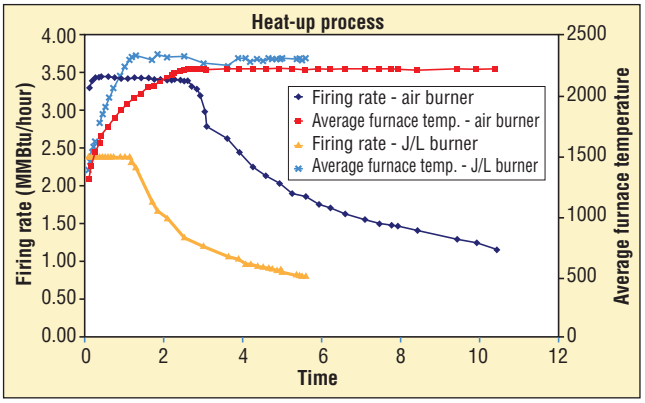


Figure 4. Typical heat-up process with air-fuel compared to DOC at test conditions

Comparison of Air-Fuel and DOC Technology

Data from the lab (Figure 4) indicates the faster heating, lower fuel consumption and quicker temperature soaking of the refractory with DOC technology compared to an air-fuel burner.

Temperature Uniformity

The combined result of DOC technology and pulse-firing control is uniform temperature distribution. DOC technology was recently installed in "box" reheat furnaces in a forge shop (Figure 5) and the temperature survey results shown in Figure 6 were obtained.

Although the specifications for this furnace required only ±25°F temperature range, the results with DOC were well within ±15°F

Figure 6. Temperature-uniformity data from new forge shop installation

Setpoint (˚F)	Avg Temp	Max Temp (+)	Min Temp (-)
1550	1552.1	9	13
1900	1901.3	10	14
2300	2299.4	11	12

of average temperature for all 14 thermocouples. In addition, the system responds quickly to temperature upsets. The temperature response after door openings was well within the required temperature range in the two-minute window required for several aerospace material grades.

Improved Combustion Efficiency

Air contains nearly 80% nitrogen, which does not contribute to combustion. If the combustion air is not preheated, this nitrogen will absorb a substantial amount of the energy produced by combustion before being exhausted through the flue. For example, in a furnace heated to 2100˚F, for an air-fired burner to provide 1 million Btu of heat energy to the furnace load, about 2.5 million Btu of energy must be provided by the fuel (Figure 7). The remaining 1.5 million Btu of energy produced by combustion of the fuel is lost to flue gases. In contrast, an oxy-fuel-fired burner loses less than 0.5 million Btu to the flue gases.

As the furnace temperature increases, an even greater proportion of heat energy is transferred to the nitrogen in the flue gas, decreasing efficiency proportionately.

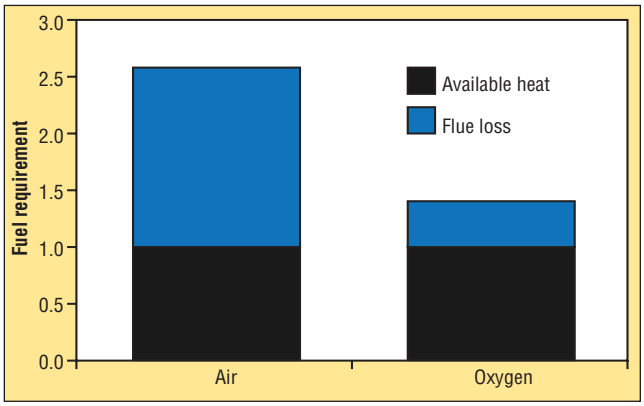


Figure 7. Estimated relationship of fuel requirement reduction and oxy-fuel

Effect of Excess Oxygen

A measurement of 2% excess oxygen in the flue gas typically indicates that the furnace has been tuned for the most efficient stoichiometric combustion whether using air or oxygen as the oxidant. A higher value indicates that excess oxidant is entering the furnace, which, in the case of air, means additional nitrogen is entering the furnace and lowering its efficiency. Air-fuel burners are often set up to operate with excessive combustion air at low firing rates to provide sufficient momentum to maintain uniform temperature distribution throughout the furnace. This leads to inefficient combustion.

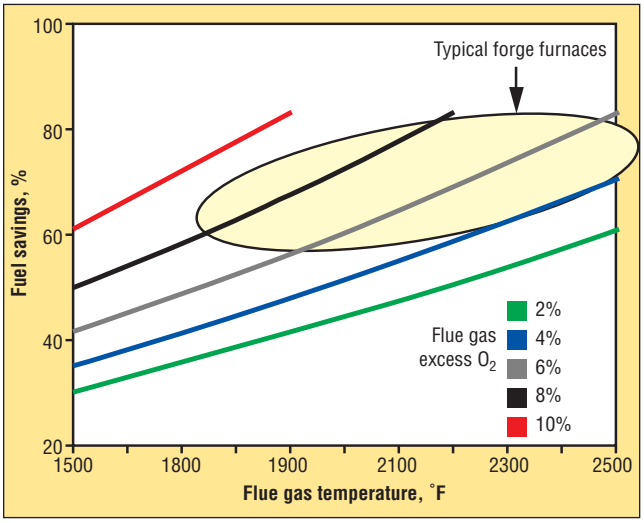


Figure 8. Estimated fuel savings with DOC for typical forge furnaces

Figure 8 shows the potential fuel savings that can result depending on the amount of excess oxygen entering the furnace and the furnace temperature. Replacing an air-fuel combustion system on a well-tuned, tight furnace would result in a fuel savings of approximately 50% at typical forging temperatures and up to 75% if high excess air had been used for uniformity purposes.

Emissions

Typically, low-NOx air-fuel burners are rated to produce about 0.1 pounds/million Btu. The amount of NOx produced by DOC will depend on the amount of nitrogen available in the furnace. Since nitrogen enters the furnace through leaks, it is very important to

Figure 9. Actual emissions data from DOC-equipped forge reheat furnace

Firing Rate %	CO	NO	CO_2	O_2	NOx (lb/mmBtu)
100	11	13	84	0.9	0.0019
90	18	15	83	1.2	0.0022
80	13	18	83	1.1	0.0026
70	16	14	82	1.1	0.0021
60	15	12	81	1.2	0.0018
50	14	14	80	1.3	0.0021
40	13	9	79	1.4	0.0014
30	13	14	77	1.4	0.0022
20	11	5	61	1.8	0.0010
10	11	5	60	2.1	0.0010
Average	14	12	77	1.4	0.0018

seal the furnace as tightly as possible. The flue size will be reduced by 80% or more from a conventional furnace and should be fitted with a damper that will close at low firing rates. Due to the very low volume of natural gas and oxygen entering the furnace, a low positive pressure will be maintained, so atmospheric nitrogen can infiltrate the furnace through any opening.

Recently, emissions measurements were made on a commercial "box" reheat furnace at a forging facility equipped with DOC technology. Figure 9 shows the results of these measurements. The measured NOx emissions, averaged over a full range of firing rates, were 0.0018 pounds NOx/million Btu.

It should also be noted that because the fuel consumption will be reduced by more than 50%, the actual pounds of NOx will also be reduced by this percentage. Carbon emissions likewise will be reduced due to the lower fuel consumption.

Conclusion

DOC technology has been proven in the laboratory and in commercial furnace installations to provide more uniform temperature distribution, lower NOx and carbon emissions and to consume less fuel than conventional combustion technologies. The addition of pulse-firing technology provides even greater capabilities. This technology is reliable to operate and easy to install and maintain. As control of emissions becomes more essential, DOC technology will play a greater role in industrial combustion.

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