

# ENHANCING COMBUSTION SYSTEMS WITH Oxygen

**Gary C. Palo and Russell Hewertson, Air Products, USA, and Petr Tlamicha, Air Products, Czech Republic, discuss the benefits of oxygen enrichment in cement manufacturing.**

Oxygen enrichment can be a useful tool for kiln pyroprocessing. Given the ever-changing global cement market, oxygen enrichment can provide manufacturers with the necessary flexibility to thrive in many economic conditions. A well-designed oxygen enrichment system can provide benefits such as incremental production gains, increased alternative fuel substitution and reduced emissions.

#### **Incremental production gain**

Combustion requires three key components: the fuel, oxygen, and a source of ignition. Fuels used in cement manufacture vary from solid fuels like coal, petcoke, tyres and other alternative fuels, to liquids such as oil and solvents, to natural gas. Once the kiln is in operation, the ignition source is typically provided by auto-ignition because the process is hot enough to ignite the fuel in the presence of oxygen. Oxygen is

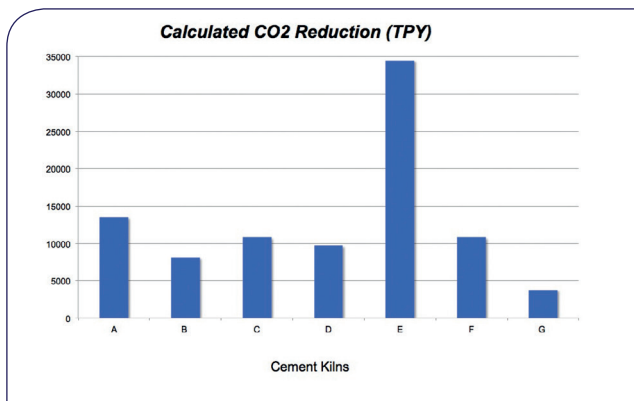


Figure 1. Calculated CO<sub>2</sub> reduction per kiln.

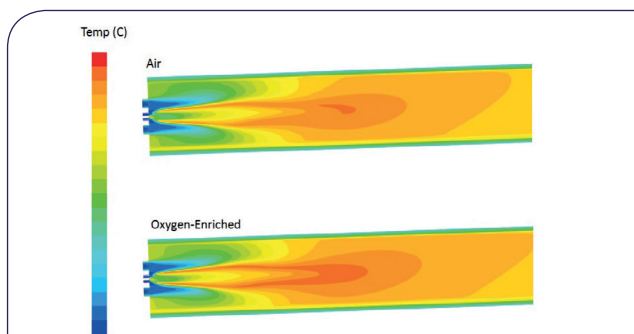


Figure 2. Examples of heat release profiles generated by CFD modelling.

typically supplied in the form of ambient air, which contains approximately 21% oxygen. The remaining 79% of air is composed of nitrogen along with other inert gases that make combustion less efficient. As the oxygen level is increased by way of enrichment with pure oxygen, the efficiency of the kiln improves. This improvement increases the available heat that can be transferred to the product and enables the kiln operator to increase both kiln feed rate and firing rate, even when the kiln had previously been induced draft (ID) fan limited, resulting in increased production.

In practice, production increases upwards of 20% have been realised when the ID fan is the limiting factor. This is combined with a reduction of specific fuel consumption of up to 5%. Typically, about four additional tonnes of clinker production can be achieved for every tonne of oxygen consumed. This ratio can be improved by matching the injection technique to a kiln's particular design.

### Increased use of alternative fuels

As conventional fuel prices continue to trend upward, the need to maximise the amount of alternative fuel grows increasingly important. Factors driving alternative fuel vary by region, but include: the relative cost of the alternative fuel to conventional fuel, the waste disposal fees for the alternative fuel in the region, emissions limitations or incentives to reduce net carbon emissions, and corporate goals to achieve greener manufacturing. It is no secret that oxygen enrichment will improve the combustibility of alternative fuels; however the injection

location of both the oxygen and alternative fuel are critical to a successful implementation. Moisture content is also important to consider when examining alternative fuels. Any moisture will require energy to be heated to the process temperature in much the same way that nitrogen requires extra energy. The moisture also places a larger demand on the ID fan due to the volume of steam it generates. Oxygen enrichment removes large volumes of nitrogen so that additional steam can be pulled through the kiln without affecting velocities and pressure drops.

Computational modelling is an important step in initiating any alternative fuel programme and one that requires extra attention as the calorific value and size distribution of the alternative fuel often differ significantly from conventional fuels. Oxygen increases the speed of combustion, providing harder-to-burn fuels the environment necessary to fully combust before reaching the charge/product.

### Reduced emissions

Oxygen enrichment can aid in the reduction of certain emissions that are caused by incomplete combustion. Carbon monoxide (CO) and other unburned hydrocarbons can be significantly decreased with oxygen enrichment. In practice, greater than 25% reductions in CO emissions have been observed using effective oxygen enrichment techniques. Sulfur dioxide (SO<sub>2</sub>) emissions, in select cases, can be reduced with proper introduction of oxygen by allowing the fuel to burn completely before exiting the air stream. This prevents the uncombusted fuel from reducing sulfur trioxide (SO<sub>3</sub>) to SO<sub>2</sub>, thus affecting gaseous emissions.

CO<sub>2</sub> can also be reduced by oxygen enrichment. With the benefits that oxygen enrichment brings to both kiln efficiency and alternative fuels, plants using this technology have reduced their CO<sub>2</sub> emissions by up to 35 000 tpy depending on alternative fuel composition, substitution rate and process efficiencies. This can be seen in Figure 1, where the calculated CO<sub>2</sub> reductions of seven kilns are documented. Allocated CO<sub>2</sub> credit for alternative fuels ranged from 0.9 – 2.5 t of CO<sub>2</sub> per t of traditional fuel reduction.

### Oxygen injection methods

The effectiveness, emissions and overall economics are often determined by optimising the way that oxygen is used by matching the technique to kiln and/or calciner design, the needs of the plant, and the regional market conditions.

### Kiln main burner

The two main oxygen enrichment methods for the kiln burner are by general or focused enrichment. General enrichment is a method of adding the oxygen to combustion air piping – typically primary air – to increase the percentage of oxygen in this stream above 21%. This method is simple to retrofit and is an inexpensive way to obtain some of the benefits of oxygen enrichment.

## Frequently asked questions

### Will I need to change my refractory to implement oxygen enrichment?

No. Air Products has used CFD modelling along with its oxygen injection technology to affect the flame shape in conjunction with the kiln burner primary air. This allows for a flame that does not degrade the protective coating or contribute to premature failure of the kiln refractory. The heat release from the burner matches the extra energy required for additional production or to allow the plant to burn alternative fuels without derating the kiln.

### Does oxygen make sense for every kiln?

No. If the kiln is not a bottleneck, market demands do not require additional production, or if alternative fuel usage levels allow the producer to meet their production needs without oxygen, then oxygen may not be justified. Oxygen enrichment of the kiln or calciner can have significant benefits for users of alternative fuels or those looking for a production increase. This is especially true for those with difficult to combust alternative fuels or ID fan limitations. Oxygen can aid in improving the efficiency of any combustion process for production increases, alternative fuel substitution, and emission issues. Air Products can work with the customer to determine if oxygen makes sense based on individual goals and market conditions.

### How easily can oxygen enrichment be added to my kiln?

Oxygen can be added to any combustion process in a short period of time and for minimal capital cost. Typically, a dedicated oxygen tank and vaporisers would be installed onsite (provided by the oxygen supplier) and the plant would install oxygen piping between the tank and the oxygen flow controls (also supplied by the oxygen supplier). The oxygen flow skid and injection equipment can either be purchased by the plant or rented/leased from the oxygen supplier. The flow controls can either be controlled by a separate PLC or more typically tied into the kiln's DCS system.

### Is oxygen safe to store at my plant?

Air Products' philosophy is, 'Nothing is more important than safety'. All storage tanks and delivery systems are built to strict codes/standards that ensure that the oxygen system is safe. Air Products will work with the plant to select an optimal location for storage tanks and provide operation and safety training for all employees associated with the oxygen system.

The second method is focused enrichment of the kiln burner. This is accomplished by adding lance(s), either within the burner or adjacent to the burner, injecting oxygen into the flame. This method of enrichment provides the most effective use of oxygen for increasing production or alternative fuel use by modifying the flame heat release profile. Special attention must be given to the burner flame shape to maximise performance and to avoid degradation of the protective coating on the kiln refractory. Often, various techniques can be used to allow the producer to adjust the flame length and heat release pattern to optimise the overall performance, economics and emissions. Proper lance design, along with the evaluation of burner primary airflow, are essential to ensuring successful implementation.


Computational fluid dynamics (CFD) has proven to be an invaluable tool when evaluating the proper method of oxygen enrichment. An example of this type of CFD modelling can be seen in Figure 2. Notice that the highest temperature zone around the core of the flame has increased, while the temperature at the walls of the kiln has remained similar to the non-enriched flame case. This can translate into increased production, increased alternative fuel use and reduced emissions.

## Calciner burners

Much like the kiln burner, both general and focused enrichment of the calciner are available options. General enrichment is accomplished by adding oxygen to an air stream that enters the calciner where the oxygen is fully mixed with preheated air before entering the combustion zone. This method, as mentioned previously, is simple and inexpensive to retrofit.

Focused enrichment of the calciner is the injection of oxygen into a defined area to aid in the combustion of a traditional or alternative fuel. This allows the oxygen to locally enrich combustion before the fuel can travel out of the calciner vessel or, in the case of alternative fuels, build up on the refractory walls. Each calciner application is different, and CFD modelling again plays a significant role in any focused oxygen enrichment solution, especially when looking to maximise alternative fuel substitution.

## Conclusion

It is important to work with a company that has both the technical expertise and a proven track record in the industry, as well as the oxygen flow controls and lance/burner/injector equipment, to provide a complete solution for implementing oxygen enrichment. Air Products has been a leader in oxygen enrichment technology for kilns and calciners for over 20 years. The company's Combustion team uses that experience, along with a state-of-the-art combustion lab utilising solid, liquid and gaseous fuel capabilities, to explore new and novel solutions to combustion and emissions challenges of kiln-based processes. 

## Bibliography

- AMBROGI, G., INSKIP, J., FARMER, L. MENKE, T., 'Enhanced Combustion', *International Cement Review* (2007).
- ARSLAN, E., CIRUCCI, J., FARMER, L., LISTERMANN, M., SHAH, J., 'Breathing life into fuel use', *International Cement Review* (2013).
- FARMER, L., KISTLER, M., YANISKO, P., 'Oxygen Economics', *International Cement Review* (2011).
- KEENA, P., BAINBRIDGE, S., 'The Power Of Oxygen', *World Cement* (2009).
- PALO, G., HUIRAS, G., 'Experience with designing complete alternative fuel solutions to meet permitted limits', *Global Fuels* (2010).
- TLAMICHA, P., FARMER, L., 'Update on Enhanced Substitution of Alternative Fuels – Recent Case Studies', *Proceedings of the 2012 Global Fuels Conference* (2012).

## For more information

Achieving a competitive edge is critical to your success. Air Products' knowledge and experience can help you achieve that edge through reliable, low-cost gas supply and proven, cost-effective technologies. Contact us today to see how we can help deliver success.

### Corporate Headquarters, North America

Air Products and Chemicals, Inc.  
7201 Hamilton Boulevard  
Allentown, PA 18195-1501 U.S.A.  
T 800-654-4567 or 610-706-4730  
T 610-363-4331 (Français)  
F 800-272-4449 or +1 610-706-6890  
gigmrktg@airproducts.com

### Europe

Air Products PLC  
2 Millennium Gate  
Westmere Drive  
Crewe CW1 6AP  
T +44 (0) 0800 389 0202  
F +44 (0) 1932 249 200  
apukinfo@airproducts.com

### Asia

Air Products Asia, Inc.  
5<sup>th</sup> Floor, Building 72  
887 Zu Chong Zhi Road  
Zhangjiang Hi-tech Park  
Shanghai P.R.C. 201203  
T +86 21 3896-2000  
F +86 21-5080-7525  
asiacmb@airproducts.com



tell me more  
[airproducts.com/kiln](http://airproducts.com/kiln)