When to enrich the kiln?

by Larry Farmer & Frank Romano, Air Products and Chemicals Inc, USA

www.airproducts.com/markets/cement

Since 1997, cement plants have routinely applied oxygen enrichment to enhance kiln performance and create economic benefit. The technical advantages of oxygen-enhanced combustion have been well documented, but there are still some questions as to its practicality, especially in the cement industry. The common perception is that oxygen works but it is expensive. While oxygen represents an added cost, it can be economical depending on operating conditions and specific costs at the plant. Other industries, such as steel, glass, and non-ferrous metals, routinely employ oxygen in their high-temperature processes.

This article addresses the economics for three common cement plant operating conditions that would warrant consideration of oxygen-enhanced combustion.

Fan limited

What first drove the use of oxygen in the late-1990s was the sudden upsurge in the USA demand for cement following years of little or no growth in capacity. As cement plants tried to squeeze extra clinker out of their kilns, they often were limited by their induced draft (ID) fans. Incremental production required additional fuel and combustion air. At most plants, the ID fan reached its limit before other equipment or systems tied to the kiln. In these cases, oxygen enrichment provided the necessary additional oxygen for combustion without the volume penalty of air (see panel). In addition to the immediate gain in incremental clinker, oxygen promotes a more stable operation by creating a hotter, shorter flame and improving burning zone control. Over time, the added stability contributes to additional production.

Since this case is purely production driven, the incremental clinker value must be greater than the added cost of the oxygen and incremental fuel and feed costs. The additional clinker is being produced with no change to the plant's fixed costs. Therefore, only the added variable costs are required to determine the net benefit. The capital cost to install an oxygen system is typically very low compared to other equipment or system upgrades and is not a significant factor in considering oxygen. In most instances, simple payback on total capital is in the order of two or three months.

The variables that play the greatest role in the economic evaluation are clinker value, unit oxygen cost, and oxygen efficiency (tonnes of incremental clinker/tonnes of oxygen). Operations that have employed oxygen for a sustained period enjoyed continued market demand for clinker with clinker values at or slightly below the cost of oxygen (on a US$/t basis) and oxygen efficiencies greater than three.

Oxygen is either produced at large cryogenic air separation plants and then transported by tank truck to the customer's site or in some cases it can be generated directly at the customer's site

Alternative fuel challenges

More and more cement plants are now turning to alternative fuels to lower their operating costs. Today's alternative fuels consist of a wide range of materials with significant variations in chemical and physical composition. Petcoke, tyres, waste oil, and chemicals were the original alternative fuels but are now being joined by a wide range of materials including wood waste, plastics, waste paper, animal meal, etc.

Depending on the nature of the fuel and its disposal cost, the economic benefits can be substantial. On the other hand, alternative fuels present a major challenge to the kiln operator. Their heating values range between 2000 and 36,000kJ/kg and they can contain up to 50 per cent water. Due to this wide range in properties, there is often a practical limit to substitution levels. In the kiln and precalciner, maintaining sufficient temperature is paramount to the efficient production of clinker. If these temperatures cannot be maintained due to the low heating values of alternative fuels, production levels must be curtailed. As a result, overall fuel substitution and the economic benefits are limited.

By increasing the flame temperature, oxygen-enhanced combustion enables increased substitution of alternative fuels without any decline in production. The economics for oxygen is driven by the cost differential between the primary and alternative fuels. To be economical, the overall fuel savings must offset the oxygen cost. This is routinely achieved at plants that are paid to burn waste fuels. When the cost differential between the primary fuel and alternative fuel is low, the added cost of oxygen is more difficult to justify unless there are other benefits.

Emission constraints

In some cases a cement plant operation is constrained by emission permit levels. When the emissions are directly related to combustion efficiency, oxygen enrichment might be feasible. For example, cement plants that are limited by total carbon monoxide (CO) emissions may benefit from oxygen enrichment. This situation typically occurs with preheater kilns burning tyres or precalciner kilns that are limited by their tertiary air.

To avoid expensive post-treatment of CO, cement plants can directly inject oxygen to react with the CO and attain some extra benefit from the resulting heat release.

The key factor in determining the benefit of using oxygen to combust excess CO is similar to the first example of increased production. The value of the additional production (or value of the high tyre substitution) must be compared to the cost of the oxygen. For CO remediation, the volume of oxygen tends to be lower than for the previous examples. The flow rate requirement also tends to be steady making on-site oxygen generation more amenable, which further improves the overall economics.

Summary

These situations all represent operating conditions that warrant investigation of oxygen enrichment. Employing oxygen injection to improve combustion in cement kilns is technically and economically viable. With minimal capital investment, cement plants can implement oxygen enrichment to gain an incremental increase in production or lower operating cost through greater substitution of alternative fuels. Each plant must weigh all options and determine the most economical approach to improve their operations. In each case, the oxygen efficiency will play a key role in the benefits analysis. The design and location of the oxygen injector are also critical to maximising efficiency. Since each plant has unique operating characteristics, it is important to consider the experience of the technology provider to make sure that optimal results are attained.

How oxygen improves combustion processes

Oxygen is required for any combustion process. Although air is the most common source of oxygen, it is not the most effective, since it also contains about 79 per cent nitrogen. Nitrogen is inert and does not contribute to the combustion reaction. The nitrogen contained in air actually inhibits fuel from reacting with oxygen and absorbs heat from the combustion reaction. This results in a flame temperature below that attainable with pure oxygen. Adding pure oxygen (oxygen enrichment) improves the overall combustion process and the resulting heat transfer by increasing flame temperature and the amount of available heat. In the kiln, oxygen enhances burning zone control and improves kiln stability. The result – more consistent kiln operation, better clinker quality, and increased production or alternative fuel substitution.

The basic principle behind oxygen enrichment is straightforward. Oxygen is added to combustion air to increase fuel rates (supplemental enrichment) or reduce overall air volume (equivalent enrichment). By substituting pure oxygen for a portion or all of the combustion air, overall gas flow rates are reduced and thermal efficiency increases. For example, $21m^3/h$ of pure oxygen can replace $100m^3/h$ of air, thereby reducing the total flue gas volume by $79m^3/h$. The benefits of oxygen enrichment can be achieved even at very low levels of enrichment.

The volumetric reduction in exhaust gases is easily illustrated by comparing the combustion reactions of air/methane and oxygen/methane. Similar reductions in combustion products occur for all fuels due to the elimination or reduction of nitrogen contained in air.

Air/Methane

$CH_4 + 2O_2 + 7.52N_2 \longrightarrow 2H_2O + CO_2 + 7.52N_2$

Oxygen/Methane

$CH_4 + 2O_2 \longrightarrow 2H_2O + CO_2$

For the air/methane reaction, there are 10.52 volumes of combustion products, compared to only three volumes of combustion products for the oxygen/methane flame. The adiabatic flame temperature of the oxygen/methane flame is roughly 800°C hotter than the air/methane flame due to the elimination of nitrogen.