

Stove Oxygen Enrichment at Arcelor Mittal's #7 Blast Furnace

Jim Bobek, Manager, Arcelor Mittal #7 blast furnace Indiana Harbor, East Chicago, Indiana

Mike Scifres, Area Manager Process Control, Arcelor Mittal #7 blast furnace Indiana Harbor, East Chicago, Indiana

Mario Hernandez, Manager, Praxair N.A.I.G., East Chicago, Indiana

James Kelly, Senior Process Specialist, Praxair R&D, Indianapolis, IN

Introduction:

Coal and natural gas prices have more than doubled in the last five years. The blast furnace, being the most energy intensive process in steelmaking, is most affected by these increases. The price of energy futures indicates the situation will not improve in the near future.

The opportunity for blast furnace ironmakers is to maximize the use of the hundreds of MMBtu/hr in top gas fuel generated by the blast furnace (BFG). The weak heating value of BFG, however, limits its utility.

A prime use for BFG is to fire the stoves that heat the blast. Since coke has become the most expensive fuel in ironmaking, maximizing blast temperature is essential to minimizing coke use. For most operations, then, the BFG alone cannot provide the temperature needed in the stove. The BFG must be mixed with a stronger, and more expensive, fuel like natural gas or coke oven gas. Surplus BFG, meanwhile, is often flared.

Theory

Analyzing the combustion of mixed fuel gas with air provides insight into a more economical alternative to expensive fuel enrichment – enriching the combustion air with oxygen. Consider the combustion of mixed gas with air to be composed of two different combustion systems – an inexpensive system burning of BFG with air and an expensive system burning of a stronger fuel, say natural gas (methane) with air. The more expensive system can be replaced by a system burning BFG with oxygen. As shown in

Figure 1, the results of BFG-O2 combustion are almost identical with the results of NG-air combustion in terms of flame temperature and the volume and composition of combustion products. The easiest way to envision the comparison is to realize that in NG-air combustion about 8000 cf / MMBtu of inert gas enters in the combustion air. In BFG-O2 combustion the same amount of inert gas enters the stove, but in the fuel rather than in the combustion air.

Since BFG-O2 combustion provides the same volume of gas at the same flame temperature as NG-air, the change is transparent from within the stove. At typical NG and oxygen pricing, the cost of oxygen enrichment is less than half the cost of NG sweetening.

Important variables in the economics are the quality of the BFG and its opportunity cost for the ironmaker. When the cost of shifting surplus BFG from cogen or boiler applications is included, the economics are generally still highly favorable, but individual situations will vary.

The higher the water content of the BFG the less NG or COG it can replace and the more oxygen that is required. Generally, the oxygen enrichment level must be limited to avoid compatibility problems between the oxygen enriched air and piping components, so de-misting of BFG can be important in maximizing the replacement of expensive fuel and the economics of oxygen enrichment.

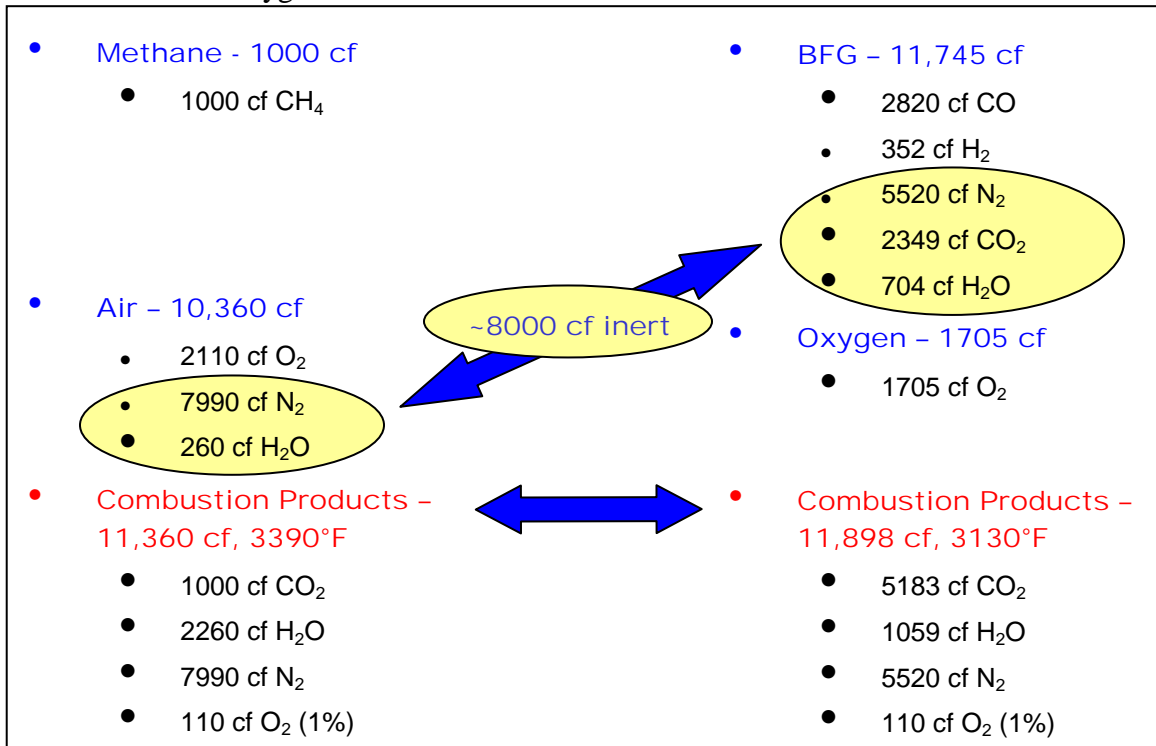


Figure 1: Comparison of the combustion of blast furnace gas (BFG) with oxygen and the combustion of Natural gas with air illustrating the similarity in combustion products and combustion temperature

Installation:

Installation of stove oxygen enrichment technology into the existing stove plant at #7 blast furnace required the installation of an oxygen delivery system to enrich the combustion air and some modifications to the stove control program. These modifications are illustrated in figure 2. The existing oxygen feed line to the blast furnace for cold blast oxygen enrichment was near capacity so an additional oxygen supply line had to be installed from the metering station to the blast furnace. This supply line was a significant extra expense for the installation.

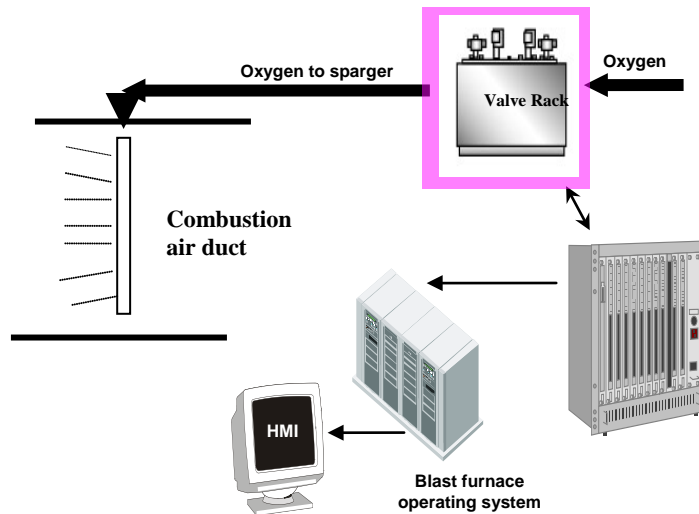


Figure 2: Equipment and modifications to existing control system required for installation of stove oxygen enrichment technology in a blast furnace

The oxygen supply skid (see figure 3) includes overpressure protection, flow control valve, and a double block and bleed to meet the strict standards for oxygen safety outlined in NFPA 86 and fabricated per the ASME/ANSI B31.3 Chemical and Petroleum Refinery Piping Code. All controls and field wiring interconnections are housed in Nema 4 enclosures. The oxygen is introduced into the combustion air through the use of an oxygen sparger designed to ensure uniform mixing of the oxygen into the combustion air. It is important that the combustion air and oxygen be uniformly mixed to avoid impingement of high concentrations of oxygen against the combustion air pipework. Uniform mixing also prevents forming local areas of high flame temperature within the stove burner. The design of the oxygen sparger was optimized through the use of a computational fluid dynamics (CFD) model.

Excessive enrichment of the combustion air could lead to very high flame temperature within the combustion chamber and overheating of the dome. With this in mind the flow of oxygen into the combustion air, is proportional to the combustion air flow itself and limited to maximum enrichment of the combustion air to 30% oxygen by volume. Furthermore, the amount of oxygen enrichment is controlled by the dome temperature measurement. When the allowable dome temperature is reached the amount of oxygen enrichment is reduced.



Results:

Figure 4 shows the trend of dome temperature over the course of a heating cycle for a stove. Obviously, a concern initially was that the dome should not get overheated. Also of concern is that the dome reach the aim dome temperature setpoint. Figure 4 shows that the dome temperature controller is able to rapidly heat the dome up to the aim temperature and maintain the dome at temperature for the entire heating cycle. This significant optimization of the stove heating is achieved by using a high amount of oxygen enrichment early in the heating cycle to drive the dome temperature to the aim. Later in the cycle the aim dome temperature can be maintained using a lower level of oxygen enrichment (see figure 5). This results in savings in the amount of oxygen

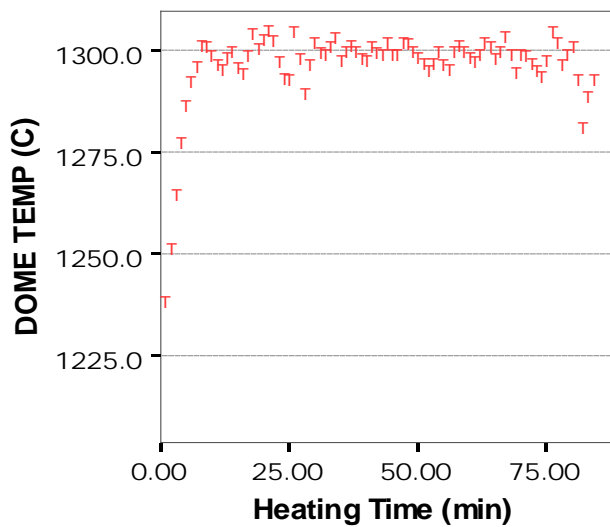


Figure 4: Temperature profile of the dome during the heating cycle

required yet also results in improved soaking of the stoves, allowing increased hot blast temperature for the same dome temperature setpoint.

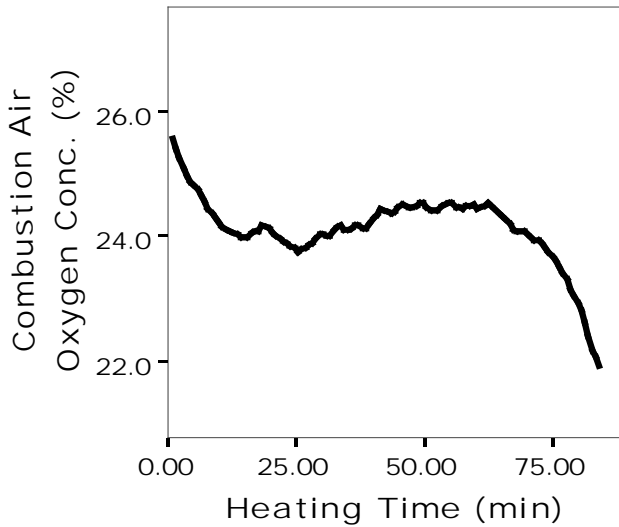


Figure 5: Variation in oxygen enrichment of the combustion air during the heating cycle (smoothed)

Figure 6 shows the trend of percent reduction in natural gas usage after startup. The natural gas usage has been reduced by about 5000 BTU per day with a relatively low oxygen consumption. There is an increase in natural gas usage in October, depicted on

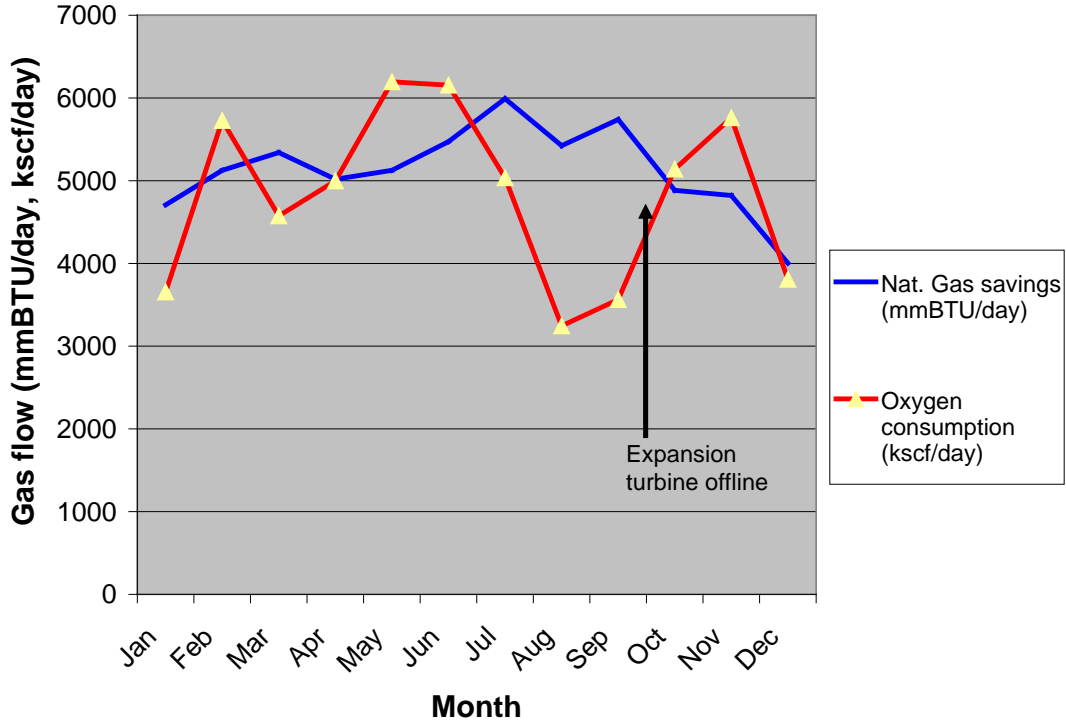


Figure 6: Trend line of the reduction in natural gas usage over time. The oxygen consumption is also shown.

the graph as a reduction in the amount of gas saved. This is associated with the top gas expansion turbine going offline and a resultant increase in the moisture content of the top gas. In order to achieve the desired flame temperature of the mixed gas, it was required to increase the proportion of natural gas to compensate for the extra moisture.

O2 Conc (%)	Moisture in BFG		
	3%	10%	10% with 0.8% NG enrichment
21	1,314	1,259	1,296
26	1,413	1,348	1,393
28	1,444	1,377	1,426
30	1,473	1,403	1,453

Table 1: Effect of blast furnace gas moisture content, natural gas enrichment level and oxygen concentration in the combustion air on flame temperature (°C). (Nominal dry BFG heating value 93 BTU/scf)

Table 1 shows that increasing the moisture content of the blast furnace gas has a strong detrimental effect on flame temperature, requiring the use of additional natural gas to compensate. The amount of oxygen consumed was considerably less than the expected. There are two reasons for this, firstly the dome temperature controller successfully reduced the average amount of oxygen required over the course of a heating cycle and secondly combustion problems on one of the stoves required that stove to be operated at a high level of excess oxygen in the stack. Operating with excess oxygen in the stack has a detrimental effect on flame temperature as illustrated in table 2. To compensate for this some level of natural gas enrichment had to be maintained to the stoves.

O2 Conc (%)	Reduction in Flame Temperature (°C)
21	89
26	73
28	68
30	64

Table 2: Effect of increasing the oxygen content in the stack from 1% dry basis to 3% dry basis for various concentrations of oxygen in the combustion air.

Effect on plugged stoves:

When the stove oxygen enrichment project was conceived, it was expected that it might help improve the firing rate on stove 1 which had significant plugging of the stove checkers. Figure 7 illustrates how stove oxygen enrichment can help increase the firing rate under conditions of stove plugging. It plots the flow resistance curve as seen by the combustion air fan under the base case condition and under stove oxygen enrichment. In the case of stove oxygen enrichment, for a given combustion air flow more mixed gas is being burned and thus there is a greater waste gas flow. Thus the flow resistance is higher for the oxygen enrichment case at a given combustion air flow. Points A and B on the graph show equivalent stove firing rates for the base and the oxygen enrichment cases respectively. It can be seen that the oxygen enrichment case the fan is operating

considerably below its capability and the firing rate can potentially be increased to point C on the fan curve, a significant increase in firing rate.

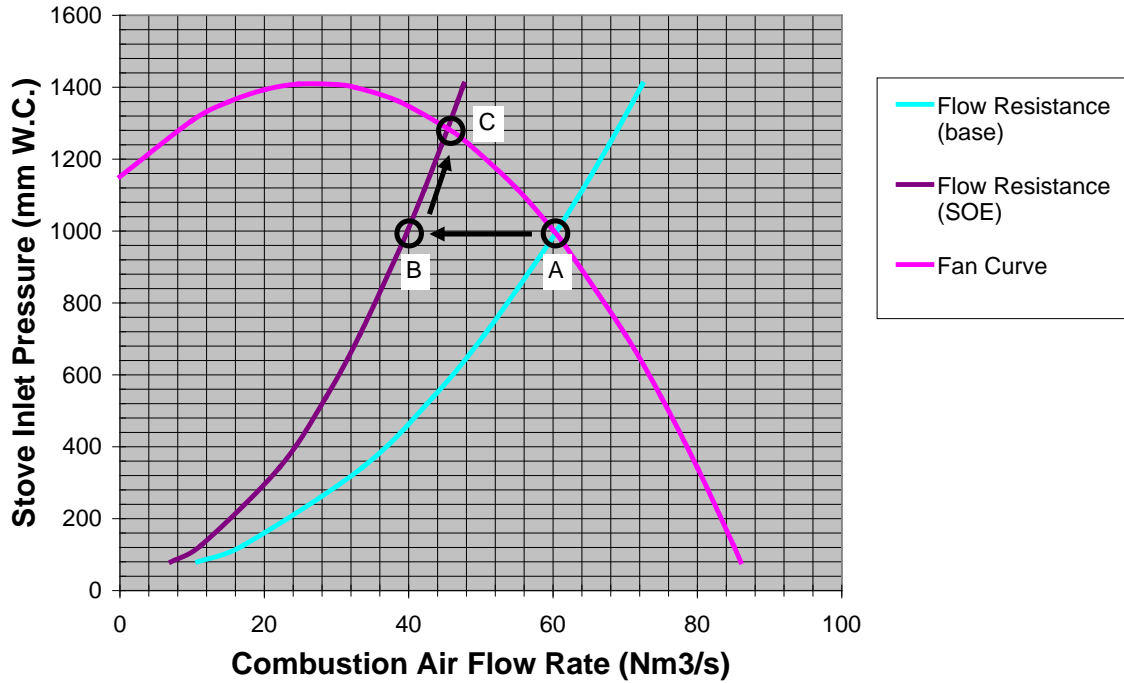


Figure 7 Effect of stove oxygen enrichment on combustion air fan operation illustrating the possibility of increasing the firing rate of the stove. Points A and B have equal stove firing rates.

Figure 8 shows the effect of stove oxygen enrichment on the maximum hot blast temperature. It plots the maximum hot blast temperature versus the wind rate under various conditions of stove plugging. For newer stoves, the stove firing rate is not limiting and the hot blast temperature is limited by the temperature constraints of the

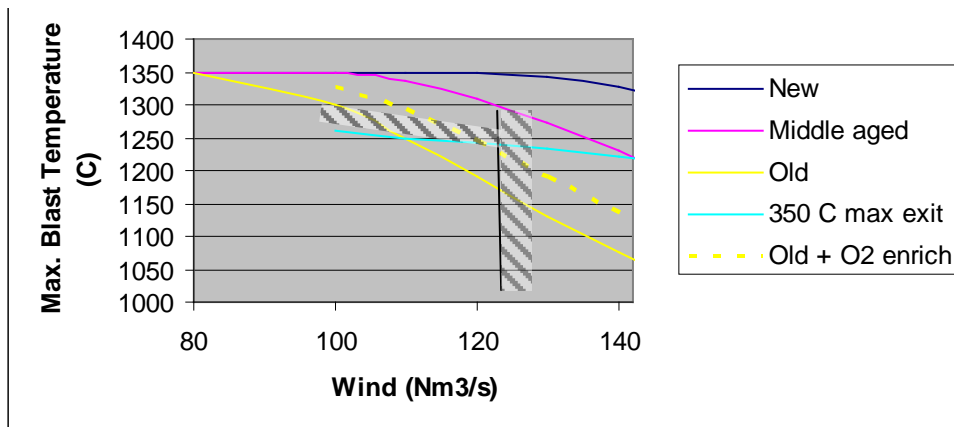


Figure 8: Plot of maximum hot blast temperature (stove firing rate limited) versus wind rate for a new, middle aged and old stove, illustrating the effect of stove plugging on stove operation. The limit lines for the turboblower capacity and maximum permissible stack temperature are also shown. Stove oxygen enrichment can significantly increase the stove output.

components of the hot blast main, of the stove dome and of the stove grid. However, as the stove checkers plug over time, the stove firing rate becomes limiting. In these circumstances, stove oxygen enrichment can increase the firing rate and correspondingly increase hot blast temperature.

Conclusions

Stove oxygen enrichment has greatly reduced the demand for natural gas for heating the stoves at #7 blast furnace. The project was installed with virtually no disruption to the operation of the blast furnace and immediately demonstrated a sharp reduction in natural gas usage. The requirement to operate one of the stoves at a high level of excess oxygen has precluded complete elimination of natural gas usage on the stoves. Implementation of a dome temperature controller served a dual function to provide inherent protection against overheating the top of the stove and to reduce the amount of oxygen flow required.
