Fuel Savings for Slab Reheating Furnaces through Oxyfuel Combustion

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ABSTRACT

With high fuel prices, fuel-savings technologies can provide significant economic benefits to steel mills. Reheating furnaces in integrated and mini-mills consume approximately half of the natural gas used to produce hot-rolled products. Recently, Praxair's Dilute Oxygen Combustion technology (previously demonstrated for productivity improvements on mini-mill billet reheating furnaces) was extended to a slab reheating furnace. This flexible oxyfuel combustion system delivered significant fuel savings with no impact on other critical process parameters (steel surface quality, emissions, refractory, oxide scale, etc.) This paper reviews installation, startup, operating results and plans for installation on other slab reheating furnaces in the hot strip mill.

INTRODUCTION

The use of natural gas in steel making has risen from 9% in 1980 to 22.5% in 2004 (WSD, 2004). This increase is largely due to the decommissioning of recovery coke ovens within the plant thereby driving the need to purchase a fuel with comparable or better heating value. Of the natural gas consumed within steel mills, a substantial fraction is consumed by reheating furnaces. Reheating furnaces within integrated mills consume ~43% of the natural gas consumed by the entire mill while the furnaces in mini-mills consume ~56% of the plants' natural gas[1]. As recently as the mid-1990s natural gas prices were less than $3.00/MMBtu. At these prices, natural gas was a small but significant fraction of the total cost of processing steel within a hot strip mill. However, through the late 1990s and early 2000s, natural gas prices have risen significantly with prices peaking at over $10/MMBtu in mid-2005. This rise in natural gas price has increased the operating costs of hot-rolling operations significantly. Operators of reheat furnaces in both integrated and mini-mills are actively looking for cost-effective, flexible technology solutions that yield fuel savings without adversely affecting steel quality, furnace productivity and environmental emissions.

Mittal Steel USA – Indiana Harbor (Mittal - IH), formerly ISG, and Praxair, Inc. worked together to integrate an oxyfuel combustion system into the reheating furnaces at the 84" Hot Strip Mill (HSM) to provide a flexible solution to their increasing fuel costs. The HSM identified several critical criteria that the oxyfuel system needed to provide. The most important of these was the ability to revert back to air/fuel firing with no operator intervention and loss of furnace productivity. Others included minimal refractory work to install the system (ideally no refractory work) and no increase in NOx emissions over the operating base case. The HSM management selected the No. 3 furnace because it had recently undergone several upgrades (recuperator revamp and new Ka-weld Phoslite forms on water cooled skid supports) and thereby represented an optimal furnace to demonstrate the technology.

FURNACE DESCRIPTION

The 84" Hot Strip Mill at Mittal Steel – Indiana Harbor produces approximately 3.8 MM tpy of hot band steel. The mill has three pusher-style reheating furnaces that were designed by Rust Furnace Co. and installed in 1968. Each furnace is equipped with recuperators to provide hot combustion air typically at 850 degrees F. Each furnace has a top and bottom primary zone, top and bottom intermediate zone and east and west soaking zone. Primary and intermediate zones are fired with hot air while the soaking zones are fired with cold air. Total installed firing capacity for each furnace is 780 MMBtu/hr. Each furnace's production rating is 280 tph. Each furnace typically operate with an average production rate of 175 tph.

OXYFUEL COMBUSTION FOR FUEL SAVINGS

Typical slab reheating furnaces operate with specific fuel consumptions in the range of 1.3 – 2.0 MMBtu/ton. Furnaces on the lower end of this range typically have long, unfired tunnels as well as recuperators that deliver combustion air at temperatures between 800-925 degrees F. Furnaces with higher specific fuel consumption typically have shorter unfired sections and may even operate without preheated combustion air. Figure 1 shows the energy distribution for a slab reheating furnace with a specific fuel consumption of 1.73 MMBtu/ton. As the figure indicates, more energy is lost to the flue than is delivered to the steel.

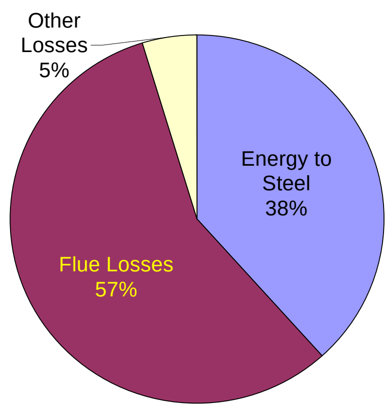
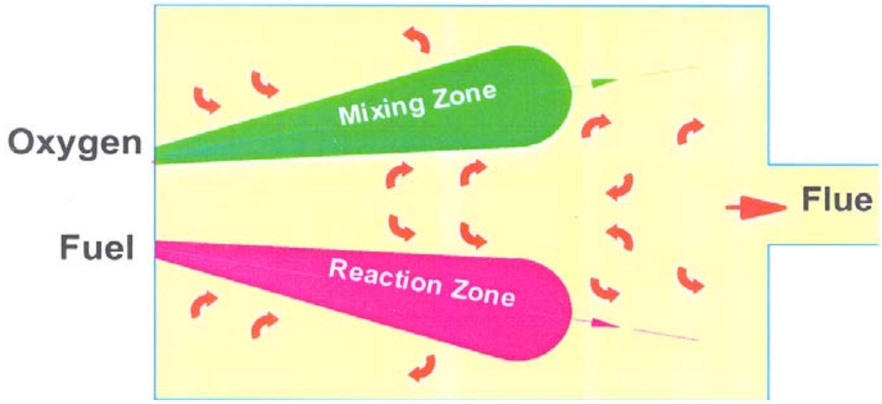


Fig. 1: Energy distribution in slab reheating furnace with hot air firing system and specific fuel consumption of 1.73 MMBtu/ton.

Combustion systems utilizing air as the oxidant have nitrogen concentrations in the products of combustion on the order of 70%. Clearly the nitrogen in the flue gases represents the largest loss of energy from the furnace as the products of combustion typically exit the furnace at temperatures in excess of 2,000 degrees F. Reduction of this nitrogen results in less energy loss from the system. Maintaining the same energy transfer to the steel, a smaller firing rate is required to close the energy balance – hence fuel savings. In practice, conversion of a portion of a furnace from air/fuel to oxy/fuel typically results in a drop in flue gas temperature. This tends to compound the benefit as both the flow rate of hot combustion products is reduced as well as their temperature.

Throughout the years, Praxair has developed a number of oxyfuel burners for various applications. The most recent of these burners for steel reheating furnace applications is the Dilute Oxygen Combustion burner. The concept of this unique combustion system is shown in Fig. 2[3]. The basic concept is to mix fuel with a hot, dilute oxidant containing 2% to 10% oxygen to produce a low peak flame temperature "reaction zone". Oxygen is injected into the furnace through a nozzle that is separated from the associated fuel jet. The injection system is designed to produce "hot, dilute oxidant" by jet entrainment of furnace gas in a "mixing zone". The reaction zone and the mixing zone are segregated within the furnace to prevent direct mixing and combustion of the undiluted oxidant and fuel. One or more pairs of oxidant and fuel jets are placed through the furnace walls to create furnace gas recirculation patterns that promote dilution of oxidant and good mixing of fuel. The stability of combustion requires hot furnace gases in this process. A minimum furnace temperature of 760°C (1,400°F) is typically preferred. As described below, the unique nature of the two injectors enabled this burner to be integrated into an existing air/fuel burner in such a way as to allow the operation of both.

Fig. 2: Schematic of Dilute Oxygen Combustion Technology



COMBUSTION SYSTEM MODIFICATIONS

After an analysis of the furnace operating data and discussions with the HSM personnel, the bottom primary zone was selected as the zone to convert. The bottom primary zone has 10 operating Bloom burners with a total zone firing capacity of 240 MMBtu/hr. Utilizing a computer model to simulate the heat transfer that occurs within the furnace, the DOC firing system was sized to maintain current furnace productivity as well as heating quality. The oxyfuel firing system provided a total zone firing capacity of 160 MMBtu/hr.

As indicated above, Mittal wanted to avoid refractory/wall work, while preserving its ability to revert to operation with the air/fuel firing system. The Dilute Oxygen Combustion (DOC) firing system[3] was selected as the technology platform for use in this installation because it had been proven successful in reheating furnace installations in the mid-1990s[3,4]. As illustrated in Fig. 2, this system is composed of two lances: a fuel lance and an oxygen lance. While all other installations involved the replacement of an air/fuel burner with a DOC burner or the addition of a new DOC burner to the furnace, this was not consistent with the objectives of the HSM management. As such, a new approach to integration was developed.

In order to minimize furnace refractory wall work, a method of integrating the fuel and oxygen lances into the air burners was developed. This design eliminated the need for any work on the furnace shell or refractory. Additionally, since the system was designed to operate on either air/fuel or DOC, but not both, the fuel flow control equipment was modified to allow the same control valve to be utilized for both modes of operation. This eliminated the cost associated with a second fuel control skid as well as additional integration work. The following sections describe the burner modifications as well as the control system modifications in greater detail.

Integration of DOC Lances into Burners

The outside diameter of the fuel lance is the same diameter as the the oil gun that was installed in these dual-fuel burners. The position of the tip of the fuel lance was designed to be at nearly the same location as the oil gun in its retracted position. This was not expected to have an impact on the performance of the burner because it was designed to operate on natural gas with the oil gun installed but retracted.

The Bloom burners have a refractory lined wind box as well as a refractory baffle. The refractory baffles contain six holes. Since DOC burners consist of a single oxygen and a single fuel lance, only one O2 lance is required per Bloom burner. The lance was designed to fit in the center of one of the holes in the refractory baffle. While the lance was located inside one of the existing holes in the baffle, the total area of the air ports was only reduced by 8.8%. With this modest reduction in area, only the high end of the burner's firing capacity was expected to be influenced. The analysis of zone firing rates indicated that the percentage of time the burner is firing at rates that would be influenced was negligible and thus the air/fuel burner performance was not expected to change significantly.

Installation of the mounting assembly that held the oxygen lance in place was done during a furnace outage. All ten of the mounting assemblies were installed in a single day. The entire DOC firing system was installed during a routine one-week mill outage. Figure 3 shows the fuel and oxygen lances installed in the Bloom burners.

(a) **(b)**

Fig. 3: Bloom burners (a) without DOC lances and (b) with DOC fuel and oxygen lances installed

Control System Modifications

All furnaces are controlled by a Bailey INFI 90 Distributed Control System (DCS). The DOC system included a relay panel that supervises the readiness of the oxygen system and manages the operation of all shutoff valves associated with the DOC firing system. The DCS monitors and manages all other transition functions. It monitors interlocks, ramps the flow controllers down to achieve the least-disruptive switchover, monitors DOC operation, and returns the zone to air/fuel firing upon command from the Operator or if the DOC System operates abnormally. The DCS monitors all permissives to both start the DOC system as well as maintain operation of the DOC system. If all the permissives are not met, the DCS will not allow the DOC system to start or will transition firing back to the air/fuel if the DOC system is in operation. The control system is designed to always fail from DOC operations back to air/fuel operations such that a DOC failure will not result in loss of capability to fire the zone.

Unlike the air/fuel system, the DOC control logic includes double cross limiting of the oxygen/fuel ratio. This maintains the oxygen-to-fuel ratio within a defined band during both the ramp up and ramp down phases of operation. This prevents periods of high-oxygen concentration in the furnace during ramping up of firing rate.

DILUTE OXYGEN COMBUSTION SYSTEM PERFORMANCE

The 84" HSM processes 12 different types of steel with multiple specifications of each. Initially, an attempt was made to analyze the performance of the DOC system on a grade-by-grade basis. However, due to the variations in hot-charge temperature, hearth coverage, delay rate and production rate for a given round type, it was difficult to identify similar cases for both air/fuel and DOC that could be compared.

The approach used to compare DOC vs. air/fuel operation was to compare monthly averages. In this way, variations in critical process parameters between round types and between turns would be averaged out. Additionally, this is more representative of the benefits to the HSM as savings are based on monthly averages not a select few turns with superior performance.

In May 2005, the mill began to decrease production relative to 2004 and the first quarter of 2005. Over the duration of the test period, the mill operated fewer days than previous months. To facilitate comparison between months, only turns with total production of greater than 1,400 tons (average production rate of 117 tph) were included in the average. This effectively eliminated startup and shutdown turns from the analysis, since they were a larger fraction of the total turns during the test period.

Table 1 shows the monthly average performance for one month operating on air/fuel and another month operating on DOC. These months were selected as they have similar delay rates, hearth coverage, hot charge percentage and average furnace production rates. As the data indicates, a 10% reduction in fuel consumption was achieved. Dividing the fuel savings by the oxygen required yields a metric used to evaluate the effectiveness of oxygen as a fuel savings technology. For the case of the DOC installation at Mittal's HSM, this value is 9.24 MMBtu/ton O2. This metric is dependent on the percentage of the heat input that is converted from air/fuel to oxy/fuel, air preheat temperature as well as the change in flue gas temperature upon conversion. This value is consistent with previous results from conversions of other furnaces[5].

The operating conditions identified in Table 1 were projected to save the HSM ~$350,000/yr per furnace at natural gas prices typical of early 2004. With the recent rise in natural gas prices in 2005, the savings realized have been significantly higher.

Table 1: Monthly average performance data for #3 reheat furnace

Month	Delay (%)	Hearth Coverage (%)	Hot Charge (%)	Avg. Prod. Rate (tph)	MMBtu/ton steel	O2 Tons/ton steel
Air/fuel	15.77	80.2	12.5	181.4	1.603	0
DOC	17.15	80.5	12.1	183.0	1.446	0.0171

The bottom primary zone is the second largest zone in the reheating furnace and thus consumes the second-largest amount of air (2,960,000 scfh maximum capacity). Conversion of the zone to DOC results in a significant drop in air flow from the combustion air fans. To estimate the savings associated with this reduced air flow requirement, an ammeter with a data logger was placed on one phase of the east and west combustion air fan motors. Table 2 shows the reduction in amperage and the associated power savings assuming a cost of $0.05/KWh. Assuming an average steel production rate of 175 tph this reduction in power corresponds to a savings of $0.015/ton steel.

Table 2: Power savings analysis for reduced air flow

Reduced load (amps)	22.42
Motor voltage	2300
Power savings (KWh)	51.57
Power cost ($/kWh)	0.05
Savings ($/hr)	2.58

NOx emissions in the flue just prior to the recuperator were measured on air/fuel operation as well as DOC. Measurements indicate that NOx emissions for operation on air/fuel as well as DOC are identical when compared on a lb NOx/MMBtu basis. Excess O2 measurements in the flue indicate significantly higher O2 (3% vs. 6%) when operating on DOC. This is believed to be due to errors in the measurement of the residual air that is leaking by the butterfly valve in the combustion air duct supplying air to the bottom primary zone. Praxair and Mittal Steel are working to resolve this measurement problem and ultimately provide NOx reductions as well.

Finally, oxide scale formation was closely monitored on the slabs exiting the reheating furnace with the DOC oxyfuel firing system installed. As has been previously observed, no difference could be detected in the quantity or quality of the scale on the slabs that were heated in the DOC equipped furnace when compared to those heated in the air-fired furnace. Scale formation in reheating furnace environments is strongly dependent on both temperature of the steel surface as well as concentration of oxidizing species. The temperature of the steel in the zone converted to DOC remained low as it was the preheat zone. Additionally, the concentration of oxidizing species remained low due to the dilution effects from the products of combustion from the bottom intermediate zone. Previous laboratory work focused on evaluating the impact of partial furnace conversion from air/fuel to oxy/fuel on scale formation showed similar results[6].

SUMMARY

Praxair's Dilute Oxygen Combustion technology has been successfully integrated into an air/fuel fired zone on a slab reheat furnace in such a way as to allow operators the flexibility to switch between air/fuel and DOC firing at will. The system has delivered significant fuel savings without imposing any additional requirements on the furnace operators. Steel processed on the furnace equipped with the DOC burners shows no difference in properties when compared to steel from those furnaces equipped with air/fuel firing systems.

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