"Efficient Utilization of Steel Mill By-Product Fuels for High Temperature Heating Processes"

by David G. Schalles
Bloom Engineering Company, Inc., Pittsburgh, PA, USA
dschalles@bloomeng.com

Abstract:

The worldwide tightening of energy supplies represents a constraint on the ongoing expansion of integrated steel production. The efficient utilization of lower quality by-product fuels represents at least a portion of the solution to this problem. Specifically, these types of fuels include Blast Furnace Gas, Coke Oven Gas, and BOF Converter Gas as well as mixtures beneficiated with natural gas. While these fuels have been commonly in use since the early years of steel production, recent environmental concerns regarding NO_x and CO_2 emissions represent a new technological challenge in this application. Modern modeling techniques and advanced control systems allow the technology suppliers to offer substantially improved combustion performance.

This paper will discuss combustion system design options and their relative impacts on efficiency, emissions and performance.

Technologies to be reviewed will include conventional/recuperative, regenerative and oxy-enriched combustion. Burner technologies have been developed to address a variety of firing configuration requirements as well as multiple fuel capabilities for maximum flexibility.

Several recent installation cases will be highlighted, including reheat furnaces, soaking pits and tube-fired atmosphere furnaces. Also included is a discussion of future technology needs and opportunities.

1) Introduction

The worldwide tightening of energy supplies represents a constraint on the ongoing expansion of integrated steel production. The efficient utilization of lower quality by-product fuels (also called 'WBPG' or Works By-Products Gases in the IFRF Handbook[1]) represents at least a portion of the solution to this problem. Specifically, these types of fuel include Blast Furnace Gas (BFG), Coke Oven Gas (COG), and BOF Converter gas as well as mixtures beneficiated with natural gas. While these fuels have been commonly in use since the early years of steel production, recent environmental concerns regarding NO_x and CO_2 emissions represent a new technological challenge in this application. Modern modeling techniques and advanced control systems allow the technology suppliers to offer substantially improved combustion performance.

The applicability of the specific data in this paper is essentially limited to Integrated Iron and Steel producing facilities due to the costs which would be associated in transporting these

[1] (IFRF Handbook Combustion File No. 253)

fuels to alternative users. Furthermore, it is generally true that Integrated steel producers' gaseous fuel requirements exceed the available by-product fuel quantities generated at a given facility.

The primary intent of this paper is to highlight the special considerations which must be addressed when selecting and designing combustion equipment for these fuels compared with conventional high calorific value fuels. Chief among these considerations would be flame temperature/efficiency, emissions, plus the effects on furnace and heat recovery equipment design.

Additionally, these by-product fuels can require extensive cleaning/conditioning facilities, gas holding tanks and costly compression, safety and distribution equipment. Suffice it to say that existing technologies which address these issues are widely known and when properly applied can result in fuels which are available at costs which remain attractive relative to externally purchased fuels.

2) Background

A detailed discussion of blast furnace gas application considerations as well as calculations methods for the calculation of beneficiation techniques is found in IFRF Combustion Files 249 through 252. Furthermore, the calculation methods of combustion parameters for any particular fuel gas composition are well known and widely available to combustion engineers. Table 1 provides a comparison of combustion properties for the primary fuels to be discussed within this paper:

Fuel Gas	Net Heating Value Typical MJ/Nm3	specific gravity Typical	Stoich air Requirement Nm3/Nm3	Stoich air Requirement Nm3/MJ	Adiabatic Flame Temp With Dissociation 500C Air Preheat 10% Excess Air Deg C	Available Heat 1000C POC Temperature 500C Air Preheat 10% Excess Air %
Blast Furnace Gas	3.22	1.06	0.611	0.190	1383	36.5
Coke Oven Gas	18.45	0.35	4.48	0.243	2108	73.8
Ladle Offgas	8.26	1.02	1.59	0.193	1974	67.4
Natural Gas	35.80	0.57	9.47	0.265	2062	73.3
Typical Enriched BFG	7.78	0.85	1.77	0.227	1856	63.4

Table 1: Combustion Parameter Comparison calculated for typical reheating furnace operating parameters

Cost data for the various fuels varies widely in different plants and locations, but it can generally be stated that the low-calorific fuels are available at very favorable costs on an overall energy content basis ($/MJ for example). Therefore, it is desirable for a steel plant to utilize all available by-product fuels in the most efficient manner possible, with consideration given to facility productivity, product quality and pollution impacts.

From the above Table 1 it is obvious that BFG by itself represents a poor fuel choice for conventional high temperature furnace operations, with a thermal efficiency of only ½ that of conventional high CV fuels. Beneficiation options therefore can include higher air preheating, BFG preheating, enrichment with higher CV fuels and Oxy-enrichment of the combustion air. The selection of the appropriate option for any given situation requires a detailed evaluation of the process and plant conditions and costs.

Currently, we find that by-product fuel utilization techniques vary widely by geographic region. While some of this can be explained by current or previous fuel economics, another reason may well be differences in philosophy and experience of the personnel involved. Specifically, we find that the use of by-product fuels (especially low CV types) for high-temperature processes is much more common within Asian and certain South American facilities than is seen in Europe or North America. And this trend is continuing, with many new facilities being erected in Asia. Recently there has been some renewed interest in studying the feasibility of retrofitting a number of sheet steel rolling facility furnaces for low CV gas firing within North America. The economics of these retrofit projects depend largely on the cost of natural gas. The availability of capital for projects of this magnitude is often a limiting factor. Nevertheless, we foresee that the interest in alternative fuels in general and low CV by-product fuels in particular will continue to increase as the pressure to reduce fossil fuel consumption continues.

3) Burner Design Considerations

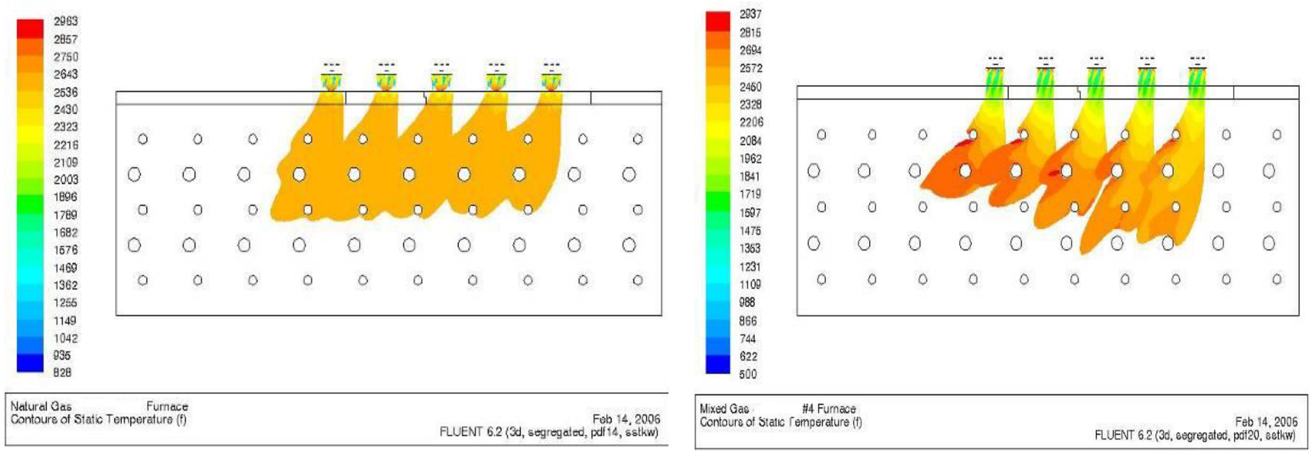
In general, burner design requirements for steel reheating applications should address a wide variety of criteria including:

1) Temperature uniformity
2) Turndown
3) Ignition and stability under cold start conditions
4) Emissions, particularly NOx and CO
5) Furnace atmosphere as it relates to product quality (scale formation)
6) Flame pattern
7) Size of equipment
8) Reliability/equipment life
9) Maintenance requirements

From our experience, we find that there are several unique properties of low-calorific value by-product fuels which need to be taken into consideration when designing combustion equipment. In fact, the overall economics of a project can be significantly affected by the combustion system requirements in terms of fuel pressure and heating value limitations. As the calorific value drops, the volume flow rate must, of course, increase. Power requirements, size of upstream compression equipment and transportation distances must be factored into the utility cost evaluation. Clearly, there will be an economic advantage by minimizing the fuel delivery pressure requirement at the burner.

In discussions of steel mill heating applications, we will limit the discussion to forced-draft nozzle mix burner designs. Typical fuel pressure availability at the burner is on the order of 50 mbar or less. However, the fuel volume flow rate is much higher than for natural gas combustion. Thus, there can be considerable mixing energy available from the fuel gas despite the velocity limitations imposed by the supply pressure. Multi-fuel capability becomes a challenge for designs which depend upon high fuel velocities. Burner designs which rely more heavily on combustion air flow geometry to achieve the desired mixing intensity and directionality tend to be more forgiving in terms of multi-fuel capability.

CFD has become a valuable tool for evaluating the effect of fuel-switching; for example, as part of an engineering evaluation of a potential alternate-fuel conversion. Heat release patterns, burner stability, furnace atmosphere and emissions can all be successfully modeled. Figures 1A and 1B compare a steel reheat furnace zone for the cases of existing natural gas and proposed mixed BFG/COG system retrofit, respectively. Such analyses can be used to determine impacts on furnace productivity, fuel efficiency and product quality.



In general, we find that these low-calorific fuels are easy to ignite and maintain a stable flame provided that the fuel nozzles are designed for velocities below the blow-off point. Given the low supply pressures, this is usually not a problem. Our testing indicates that the presence of even low percentages of Hydrogen tend to widen the ignition and stability limits of these burners. One exception can be the case of lean Blast Furnace Gas produced in certain operations with low CO/CO2 ratios in the blast furnace top section[2]. Our experience indicates that a stable and detectable flame can be obtained even with cold combustion air at 3.0 MJ/Nm^3 LCV gas. Below this value the BFG must be beneficiated in some way to achieve stable combustion.

As illustrated in Table 1, the theoretical flame temperature of these fuels is a direct function of the heating value, up to the point that the inert constituents become insignificant. Thus, the very lean fuels such as BFG, LDG and enriched BFG are already 'vitiated' by the presence of N2, CO2 and other inerts. Interestingly, some manufacturers have begun to combine higher CV fuels with inerts for the purpose of NOx minimization. For example, the technique of blending FGR with natural gas prior to combustion can result in a fuel with similar properties to the BFG/COG mixed gas. Steam injection would be a further example of this technique. In addition to NOx minimization, a further benefit of this technique is improved temperature uniformity within the firing chamber.

[2] "Industrial Furnaces", Trinks and Mawhinney 4th ed. Vol. 2 p.12

For this reason, the very Low CV fuels can generally be considered as contributing to reduced thermal NOx formation. By contrast, Coke Oven Gas tends to produce significantly higher levels of NOx (relative to natural gas) due to the high flame speed of the Hydrogen fraction (typically 55-60%) as well as the presence of organic nitrogen compounds such as NH3 and HCN. Our findings lead to the conclusion that it is not feasible to determine accurate NOx adjustment factors for different fuel types. Testing and modeling are necessary to predict the effect of a fuel change for each specific burner design and application.

4) Heat Recovery Options

The most common technique for flue gas heat recovery in steel reheating and other high temperature furnace processes is to preheat the combustion air using recuperation or periodic-regenerative heat exchange. However, very low CV fuels such as BFG, mixed BFG/COG and LDG will still exhaust a large amount of additional waste heat because the combustion air can only absorb a fraction of the potential waste heat. Waste heat flow is calculated as mxCpxDT:

1) The specific heat of the air is significantly lower than typical Products of Combustion (Cp(air)= 0.260 keal/kg-^{o}c at 1000 C compared with Cp(POC) = 0.312 kcal/kg - ^{o}c[3]

2) The air/POC flow mass ratio is significantly lower with these fuels due to the high inert levels in the fuel, plus the lower stoichiometric air requirement for CO compared to HC fuels. Thus, the air/POC flow mass ratio is about 0.94 for natural gas but about 0.34 for typical BFG.

3) Even with a very efficient periodic-regenerator system, the Delta T of air preheat will approach only about 90-92% of the POC available Delta T.

The results of these factors are evident from the Available Heat example values shown in Table 1. It is evident that additional means of waste heat recovery may become economically desirable for low CV fuels of this type. The most common employed forms of additional heat recovery for these applications are:

1) Recuperative fuel preheating. A metallic heat exchanger is added to the flue duct for the purpose of preheating the fuel gas in addition to the air. In practice, this can provide fuel preheat levels as high as 500-600C. Special fuel train components and burner nozzles will be needed to handle the increased temperature and volume of the fuel.

2) Waste heat boiler. When other plant processes present a need for steam, this can be a viable option. However, it must be recognized that the furnace and mill operation cannot always be synchronized with the steam demands. Mill production will inevitably take precedence. Use of waste-heat steam for power generation has been suggested, but the economics are generally not favorable due to the high capital costs.

[3] Technical Data on Fuel, published by The British National Committee, World Power Conference, p.178

3) Regenerative fuel preheating. This basic technique has been well known in applications such as coke ovens and open-hearth steel furnaces for over a century. However, the application to reheating and other process furnaces seems to be a recent development. The use of compact regenerators employing short cycle times has been applied for about 20 years for combustion air preheating, but is only starting to be utilized for low CV fuel preheating. Fuel temperatures as high as about 1000C can be achieved with this technique bringing the Available Heat for a BFG-fired system to about the same level as a natural-gas fired furnace with regenerative air preheating. One caveat here is that the presence of Hydrocarbons in the fuel can lead to ‘cracking’ and sooting within the regenerator media. An empirical guideline in the industry has been to keep the level of ‘rich’ fuel enrichment of BFG below about 10% by volume to avoid sooting in the regenerator. However, this becomes a function of HC type, concentration, residence time and temperature gradients. Our company is currently conducting R&D to study these variables, which must be quantified in order to optimize such a heating system for a given fuel type.

   Furthermore, regenerative fuel preheating presents significantly greater challenges for the burner designer in terms of materials and flow geometries. Note that the entire ‘burner’ must additionally serve as a flue duct during the heat recovery portion of its cycle. Thus, the components will be subjected to flue gases essentially at process zone temperature (as high as 1300C in a steel slab reheating furnace). Ceramic/refractory components therefore must be utilized in these passages. Care must be taken to maintain separation between the fuel and air passages within the burner.

5) Furnace Design Considerations

Our experience has shown that the combustion volume requirements for these fuels in high-temperature applications is similar to higher CV fuels such as natural gas. Therefore ,it is often feasible to retrofit existing chambers to low CV fuel firing. However, there are additional factors which must be considered in the proper application of such fuels:

1) Flame temperature and available heat. In simplistic terms, the closer the flame temperature approaches the process temperature the lower will be the resulting combustion efficiency. It is obvious that the theoretical flame temperature of a fuel must exceed the required control temperature of any given region of a heating furnace. In fact, this consideration is the primary reason that periodic regenerative systems were employed early on in such very high temperature processes such as glass melting and open-hearth steel production.

2) The analysis of a multi-zone furnace requires that each zone be analyzed for sufficient ‘available heat’, not just the overall process. When analyzing a potential retrofit of an existing furnace to low-CV fuel, the result will show that the highest temperature zones may require substantially higher gross fuel input to achieve the desired net. However, in the case of a continuous furnace such as a steel reheat, there will be a greater volume of ‘carryover’ gases which will reduce the heat requirements in the lower-temperature downstream zones. Thus, a detailed furnace calculation is required.

6) Control System Considerations

By-product and other off-gases will generally be subject to variations in composition at the production source. Batch processes such as ladle degassing will yield a significant variation in heat content, inerts and oxygen content throughout the course of the operation. More continuous operations such as blast furnaces yield a more steady composition of the off-gas. While coke ovens themselves are batch in nature, they are arranged in ‘batteries’ such that the net result is a relatively constant source of gas. In a large integrated steel plant, the careful management of these fuel sources becomes a significant effort. Equipment such as gas holders, blending stations and on-line analyzers are used to minimize the variabilities in the plant fuel supply.

A common method of maintaining steady combustion characteristics is to control a fixed Wobbe index (calorific value divided by the square-root of specific gravity). While this provides a constant heating fuel flow for the same metering delta-P, it does not address the variation in air requirements for different compositions. In general, this is not a significant error for hydrocarbon fuels, but can yield substantially incorrect results in the case of blast furnace gas with a high percentage of Carbon Monoxide. An alternate method that is commonly used for furnace control is the Combustion Air Requirement Index Meter, which can be used to provide on-line corrections to air/fuel ratio control.

In other cases, it may be desirable to maximize the use of the lowest cost fuel and supplement as necessary with higher cost (i.e., higher CV) fuels. This requires a more complex control system for fuel management and combustion. In addition, this can necessitate special burners which can operate over a wide range of fuel conditions and flows. Multiple fuel system piping to a large number of individual burners is generally avoided where possible. A blending system is used which can feed-forward the real-time fuel composition to allow the temperature and ratio-control systems to compensate. This strategy has also been successfully implemented in a steel plant which happened to be located in close proximity to a municipal landfill. The LFG (about 45% CH_4 with balance inerts) is used as a base load fuel with natural gas supplementation as needed.

Contaminants and trace components in the by-product fuels can present further problems for burners, control valves and metering devices. Naphthalene and tar are often contained in coke oven gas, while blast furnace gas may contain significant dust loading and even water vapor ‘slugs’. There is wide variability in the gas cleaning and conditioning systems from plant to plant. Effective countermeasures for each have been developed, but it behooves the combustion system engineer to be sure that these have been properly addressed for the specific fuel within the particular plant.

7) Recent Applications

To illustrate the wide applicability of advanced systems for combustion of WBPG to steel mill heating processes, we wish to highlight a few of our recent projects:

A) Steel Reheating Furnaces
Location: China
Product to be Heated: Steel Slabs
Fuel: Mixed BFG/COG at 2000 kcal/Nm^3
Combustion Air Temperature; About 580 C
Fuel Temperature: Ambient

Ultra Low NOx side-fired burners

Roof-mounted flat profile flame burner

B) Steel Soaking Pit Furnaces
Location: China
Product to be heated: Steel Ingots
Fuel: Mixed BFG/COG at 1800 kcal/Nm^3
Combustion Air Temperature; 1000 C (Regenerative)
Fuel Temperature: 400 C (Recuperative)

Paired Regenerative Burners

C) Steel Reheating Furnaces
Location: China
Product to be heated: Steel Slabs
Fuel: Mixed BFG/COG at 2200 kcal/Nm^3
Combustion Air Temperature; 1000 C (Regenerative)
Fuel Temperature: Ambient

Side-fired Regenerative Burners

D) Steel Reheating Furnaces
Location: China
Product to be heated: Thin Steel Slabs
Fuel: Mixed Gas
Combustion Air Temperature; 500C (Recuperative)
Fuel Temperature: 350C

CSP Tunnel Furnaces

E) Continuous Steel Galvanizing
Location: China
Product to be heated: Steel Strip
Fuel: Mixed BFG/COG at 2200 kcal/Nm^3
Combustion Air Temperature; 400C (Recuperative)
Fuel Temperature: Ambient
Radiant Tube-fired Atmosphere Furnaces

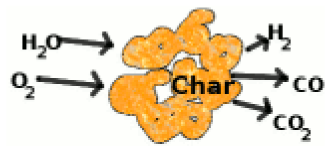
Vertical Strip-heating furnace with radiant 'W'-tubes

Thus it can be seen that WBPG fuels can be widely applied to a variety of heating processes and combustion configurations within an integrated steel plant. Extremely low emissions, excellent product quality and high fuel efficiency can all be achieved with such fuels, provided that the combustion and furnace equipment is properly designed for the particular fuel characteristics.

8) Future Development Opportunities

Because these fuels are by-products from steel and coke production, the amount available at each plant is limited and normally does not fully meet the demands of the plant wide facilities. Given the rising costs of purchased fuels, it is imperative that each plant maximize the efficiency with which these fuels are utilized. Technologies such as regenerative fuel preheating are becoming cost-justified and further improvements in safety and reliability of such systems are needed.

Additionally, similar fuels such as 'producer gas' could be manufactured from coal, coke or even Biomass on-site at any industrial-scale user. Such devices were commonly used in the United States prior to the widespread availability of natural gas. Coal gasification technology for combustion processes is likely to be based on similar principles utilizing the water gas reaction.[4]



The high costs of capital equipment including extensive flue gas cleanup has limited the feasibility of such projects. However, a future optimized technology can be envisioned in which oxygen-blown coal (or biomass) gasification would yield a gaseous fuel with primarily H20 and CO2 combustion products. This would then minimize the difficulty and expense of carbon sequestration.

In summary, the technology for efficient and clean utilization of low CV fuel is now well-proven and available for a variety of steel heating processes. Such technology will make the use of similar manufactured fuels feasible in a wider variety of industrial processes.

[4] Wikipedia 'Gasification'