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

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INTRODUCTION

Scope of this paper

• Why is this an area of interest for combustion engineering?
  • Alternative fuels, energy and environmental topics
• Discussion is limited to steel heating processes
  • However, these concepts would often be applicable for other LCV fuel sources such as Biogas, producer gas, etc.
• Differences compared to high CV fuels
• Review of some recent applications
Definition

- **Works By-Product Gases (WBPG)**

  From IFRF Handbook Glossary:

  “General name given to useful gaseous fuels produced during the production of iron and steel and utilised within an integrated steel works for process heating and power generation.”
DIFFERENCES COMPARED TO HIGH CV FUELS

- Efficiency/flame temp may be much lower
- Emissions will be affected
- Furnace performance and heat recovery issues
Combustion Parameter Comparison calculated for current typical reheating furnace operating parameters

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

A good source for unit conversions:
www.onlineconversion.com
BACKGROUND/REFERENCES

- IFRF Combustion Files on BFG beneficiation: Numbers 249 through 253
- These files provide data for calculating flame temperatures, efficiency and generalized NOx with:
  - Enrichment
  - Oxy-enrichment
  - Air Preheating
  - Fuel Preheating
How do I estimate the effect of beneficiation on the efficiency of BFG fired furnaces relative to natural gas firing?

A Combustion File downloaded from the IFRF Online Combustion Handbook
ISSN 1607-9116

Combustion File No: 250
Version No: 1
Date: 20-10-2003
Author(s): Neil Fricker

IFRF Studies on the Utilisation of Works By-Product Gases in the Iron & Steel Industry
A Review Prepared by:

Neil Fricker and Jeff Rhine
University of Glamorgan
BACKGROUND

- Current utilization in high-temp processes
  - Common in Asia and South America
  - Rare in USA (except coke gas) – why?
    - Given that by-product fuels are not produced in excess for most integrated steel works.
    - Therefore energy savings can be ‘on the margin’ to reduce consumption of the high CV purchased fuels.
  - Have been diverted to steam/cogen projects
BURNER DESIGN CRITERIA

When evaluating the use of Low CV fuels, consideration must be given to:

1. Temperature uniformity/heat flux
2. Turndown
3. Ignition and stability, especially 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
BURNER DESIGN CONSIDERATIONS

Differences compared with high CV fuels

- High volume of fuel affects mixing patterns
- Need to minimize supply pressure requirement (typically under 50 mbar)
- Multi-fuel burners must address wide range of fuel velocities
  - This fact tends to favor designs which rely heavily on combustion air flow geometry for mixing and flame direction
BURNER DESIGN CONSIDERATIONS

- Can be similar to ‘flameless combustion’ regarding Low NOx – fuel is already in effect ‘vitiated’ with inert
- Some manufacturers utilize vitiation principles to generate a low CV equivalent from natural or other high CV gases, to reduce NOx
BURNER DESIGN CONSIDERATIONS

Radiant tube firing - additional considerations

- Lower flame temp/heat transfer – higher POC temps
- Vitiated fuel – improves tube uniformity and NOx
- May need a high CV fuel if using a constant pilot burner
Heat Recovery Options

- Recuperative Air Preheating
- Regenerative Air Preheating

\[ \dot{m} \times c_p \times \Delta t = Q \]

- There is much more heat available in the POC than can be transferred to the combustion air
Heat Recovery Options (Cont’d.)

- Fuel Preheating
  - Considerations
    - Safety - requires special equipment designs
    - Soot potential/cracking of HC’s
    - OK <10% by volume of Natural Gas. Is this ‘rule of thumb’ valid? Some Research is needed
Heat Recovery Options (Cont’d.)

Oxygen Firing

• This greatly reduces the volume of waste heat
• Oxygen as comburent, combined with BFG preheating provides a highly efficient option in theory.
• As always, the economics would be a function of oxygen cost. We are not aware of an industrial scale installation using this combination.
Furnace Design Considerations

- May need to allow for larger combustion space
- Consider available flame temperature and zone available heat. In a retrofit, high temperature zones may require substantially more gross input. The furnace heating calculations must be run. It is not as simple as matching the previous high CV inputs.
- Uniformity – CFD can be an ideal tool for ‘what if’ scenarios
Natural Gas Firing

CFD Simulation

Plan view of Bottom Heat Zone- West Side
Mixed BFG/COG Firing

CFD Simulation

Plan view of Bottom Heat Zone - West Side
Control System Issues

- Variability of heating value and composition
- Requires an on-line analyzer somewhere in the utility supply system. Primary concern is to maintain the correct stoichiometric ratio
- Component considerations – contaminants:
  - Must be suitable for sulfur – no brass or aluminum
  - Tar, naphtalene, or dust can clog piping and orifices. Consider over-sized piping and valves, segmental orifice meters, etc.
Some Recent Applications Utilizing Low CV By -Product Fuels

- Ultra Low NOx hot air burners – steel reheat furnaces
- Regenerative direct-fired burners – reheat furnaces (continuous process)
- Soaking pits with regenerative air/recuperative fuel preheating (batch process)
- Compact strip tunnel furnaces
- Radiant tube burners for steel strip lines
Fuel: Mixed BFG/COG at 2000 kcal/Nm³
Combustion Air Temperature: About 580 C
Fuel Temperature: Ambient

Hot Strip Mill Reheat Furnace
Ultra Low NOx side-fired burners with adjustable flame
Hot Strip Mill Reheat Furnace

Ultra Low NOx side-fired burners with adjustable flame

Fuel: Mixed BFG/COG at 2000 kcal/Nm³
Combustion Air Temperature: About 580 °C
Fuel Temperature: Ambient
Steel Reheat Furnace
Ultra Low NOx Roof-mounted flat profile flame burner

Fuel: Mixed BFG/COG at 2000 kcal/Nm³
Combustion Air Temperature; About 580 °C
Fuel Temperature: Ambient
Mixed BFG/COG at 1800 kcal/Nm3

Regenerative Air 1000 C

Recuperative Fuel Preheat 400 C

Steel Soaking Pits
Paired Regenerative Burners
Hot Strip Mill Reheat Furnace
Side-fired Regenerative Burners

Fuel: Mixed BFG/COG at 2200 kcal/Nm³
Combustion Air Temperature; 1000 C (Regenerative)
Fuel Temperature: Ambient
Regenerative Heat Storage Ball Media Ready for Re-use After Cleaning.

Typical Lifetime > 5 yr

Vacuum truck system is one convenient way to remove and clean media
Hot Strip Mill Reheat Furnace
Side-fired Regenerative Burners

Fuel: Mixed BFG/COG at 2200 kcal/Nm³
Combustion Air Temperature: 1000 °C (Regenerative)
Fuel Temperature: Ambient
Design Parameters

Fuel Consumption 10% less than conventional recuperative furnace

Under 50ppm NOx at 11% O2
  (actually achieving <35 ppm)

Furnace Uniformity < 50C across width

Scale loss <0.7%
Hot Strip Mill Regenerative-Fired Reheat Furnace
First Hot Slab!
Fuel: Mixed Gas
Combustion Air Temperature: 500°C
(Recuperative)
Fuel Temperature: 350°C

CSP Tunnel Furnaces
Steel Galvanizing Strip
Vertical Strip-heating furnace with radiant ‘W’-tubes

Fuel: Mixed BFG/COG at 2200 kcal/Nm³
Combustion Air Temperature; 400C (Recuperative)
Fuel Temperature: Ambient
Next Steps

- Retrofit issues – especially for USA
  - (note that all of the preceding projects were new furnaces)
- Studies are showing that operating economics would favor using By-product fuels to replace natural gas in heating processes, as compared to using for steam-cycle power generation
- Capital costs for retrofits are typically high, while companies often seek 12-18 month payback
For Future Study- Alternate Low CV fuel sources

- CO₂ emission considerations and supply of natural gas will be ‘drivers’

General ‘Water-Gas’ Reaction of coal or biomass
- Oxy-fuel combustion of this Low CV gas would allow CO₂ capture, but is it justified?
- Ultimately we expect to see expansion of gasification technology into industry
Questions . . .

Comments . . .