Regenerative Firing vs. Oxy Fuel Firing: An Applications Approach

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KEY WORDS

Combustion
Oxy Fuel
Regenerative Burners
Reheat Furnace
Fuel Savings

INTRODUCTION

Over the past fifteen years, furnace designers and operators have sought creative new ways to save fuel and increase production. Many ways have been tried but at the forefront are Oxy Fuel and Regenerative firing. This paper will evaluate both concepts as they apply to continuous and batch reheat furnaces. Although the furnaces are contrived, they are representative of actual furnaces encountered in the steel industry.

Regenerative Burners

Regenerative burners are typically installed in pairs. When one burner fires, the other is exhausting through the burner head, media and media case. The hot exhaust gases transfer heat to the media where it is stored until the cycle reverses. After reversal, the burner that was firing becomes the flue, while the burner that was exhausting now begins to fire. The cold combustion air passes through the heated media where the stored energy is recovered. Very high air preheat levels are typically achieved, making the regenerative burners extremely efficient.

Oxy Fuel Burners

Oxy fuel burners burn fuel with pure oxygen. By eliminating the nitrogen from the combustion the quantity of combustion air is reduced by 80% making the combustion extremely efficient. The waste gas quantity is reduced accordingly and significant fuel savings can be affected.

PURPOSE

Both Continuous furnaces and batch furnaces will be evaluated with respect to regenerative firing and oxy-fuel firing. Having completed this, hybrid configurations, oxygen enrichment, and dual blast furnace gas regenerative will also be evaluated for the continuous furnace.

For the continuous furnace side, a top and bottom fired walking beam furnace will be evaluated and for the batch side a car bottom furnace will be evaluated.

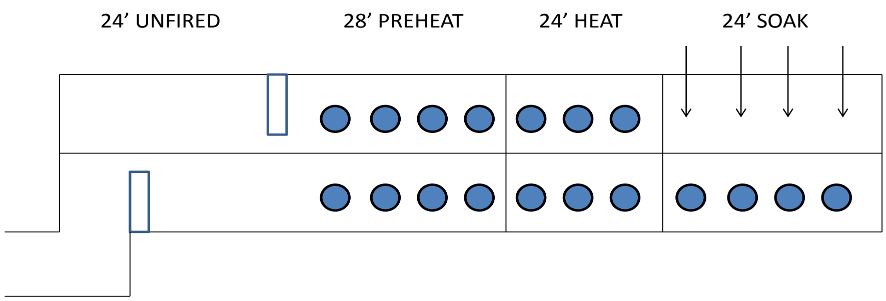
CONTINUOUS REHEAT FURNACES

In order to evaluate these concepts a furnace typical of many in steelmaking operations will be evaluated for both modes of firing. This typical furnace is shown below. The results generated from this particular furnace example do not imply any specific performance guarantee. The following are the parameters for this furnace:

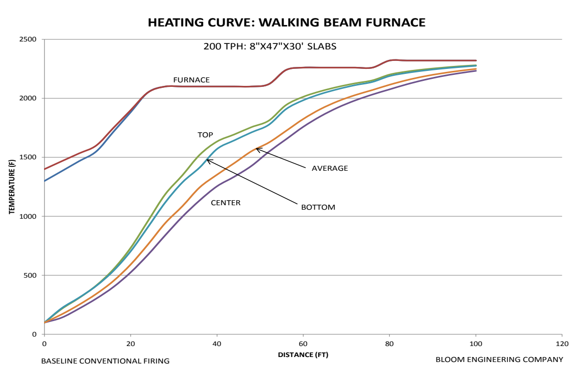
- 200 TPH Walking Beam
- 100' Effective Length

- Six Zones (3 Top 3 Bottom)
- 8”x47”x30’ Slabs
- Natural Gas Firing
- 850 F Air Preheat
- 2250 F Average Discharge Temperature
- Carbon Steel

CONTINUOUS FURNACE
200 TPH



The following is the heating curve for this furnace:



The following is the associated heat balance:

INPUT	MMBTU/HR	%	OUTPUT	MMBTU/HR	%
TOTAL GROSS FUEL	248.901	86.64	HEAT TO STEEL	142.963	49.76
HEAT FROM HOT AIR	38.396	13.36	HEAT TO WATER	16.850	5.86
			HEAT TO INSULATION	5.791	2.02
			HEAT TO SLOTS	3.326	1.16
			HEAT TO DOORS	1.000	0.35
			ROLLS	0.000	0.00
			WASTE GAS LOSSES	92.477	32.19
			LATENT HEAT OF WATER VAPOR	24.890	8.66
TOTAL	287.297	100.000	TOTAL	287.297	100.000

FUEL RATE: 1.245 MMBTU/Ton

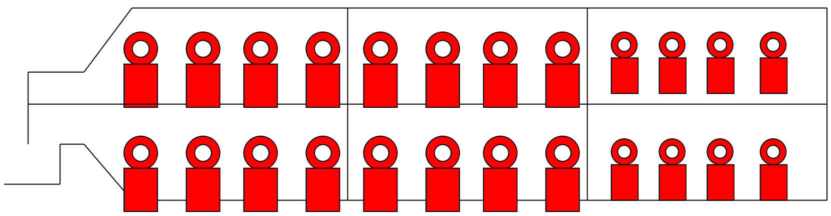
Regenerative Furnace

The furnace shown is fired with conventional hot air burners. When using regenerative or oxy fuel burners, the amount of waste gases leaving the furnace through the flue is greatly reduced. Thus the importance of heat losses through the flue is lower and the length of the unfired section of the furnace can be reduced, since flue gas temperature is not as critical.

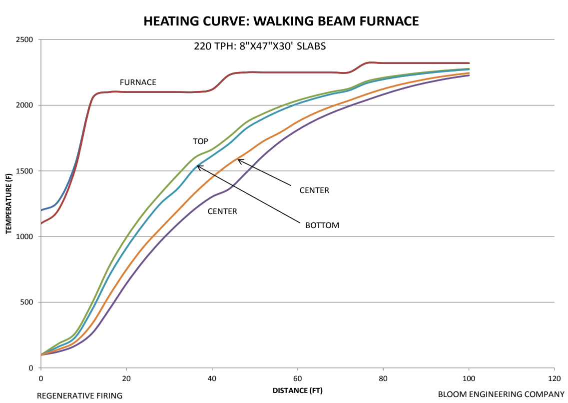
Since the unfired section is shorter for the regenerative and oxy fuel firing, the same size furnace is capable of producing a slightly larger tonnage, so the subsequent continuous furnaces will have a larger throughput.

The following is a typical furnace that would be designed for regenerative burners. The throughput is 220 TPH at the same effective length of the conventionally fired furnace presented above.

REGENERATIVE FURNACE
220 TPH



The following is the heating curve for this furnace:



The following is the associated heat balance:

INPUT	MMBTU/HR	%	OUTPUT	MMBTU/HR	%
TOTAL GROSS FUEL	230.792	100.00	HEAT TO STEEL	157.260	68.14
HEAT FROM HOT AIR	0.000	0.00	HEAT TO WATER	17.158	7.43
			HEAT TO INSULATION	5.790	2.51
			HEAT TO SLOTS	3.638	1.58
			HEAT TO DOORS	1.000	0.43
			ROLLS	0.000	0.00
			WASTE GAS LOSSES	22.867	9.91
			LATENT HEAT OF WATER VAPOR	23.079	10.00
TOTAL	230.792	100.000	TOTAL	230.792	100.000

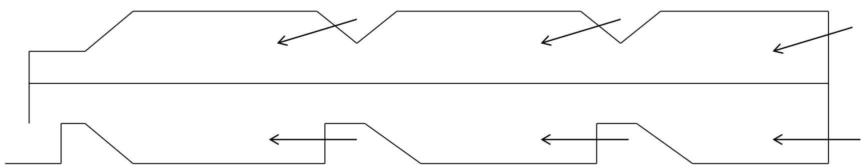
FUEL RATE: 1.049 MMBTU/Ton

Oxy Fuel Furnace

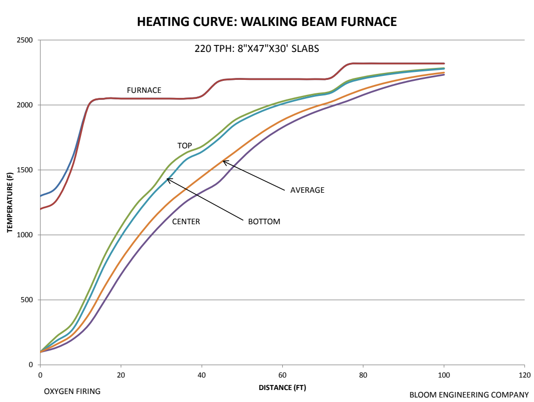
The oxy fuel furnace will be fired longitudinally rather than side fired because the flame envelope is much smaller. The zone height will be lowered as well to accommodate the smaller burner size. As before, the unfired section will be shorter and the throughput will be raised to 220 TPH.

The following is a typical furnace that would be designed for oxy fuel firing.

OXY FUEL FURNACE
220 TPH



The following is the heating curve for this furnace:



The following is the resultant heat balance:

INPUT	MMBTU/HR	%	OUTPUT	MMBTU/HR	%
TOTAL GROSS FUEL	231.886	100.00	HEAT TO STEEL	157.260	67.82
HEAT FROM HOT AIR	0.000	0.00	HEAT TO WATER	17.680	7.62
			HEAT TO INSULATION	4.632	2.00
			HEAT TO SLOTS	3.987	1.72
			HEAT TO DOORS	0.300	0.13
			ROLLS	0.000	0.00
			WASTE GAS LOSSES	24.838	10.71
			LATENT HEAT OF WATER VAPOR	23.189	10.00
TOTAL	231.886	100.000	TOTAL	231.886	100.000

FUEL RATE: 1.054 MMBTU/Ton

OPERATING COSTS

The continuous furnaces are now evaluated on their operating costs. The major differences in the operation of these two furnaces are in the way that fuel is burned and amount of electricity and oxygen consumed for the oxidant delivery.

The operating costs are based on the furnace operating continuously at the rated tonnage. No delays are considered. The electrical costs have been developed on running horsepower and not connected load.

The following is the basis for determining the utility costs:

- Fuel Cost $3.37/1000 SCF
- Electricity $0.075/KWH
- Oxygen $0.20/100 SCF
- Total Fuel 232 MMBTU/Hr Both Case
- 561 Operating Horsepower for Regenerative Fans
- Total Oxygen 497,640 SCFH

The following are the operating costs for the regenerative furnace:

- Fuel $781.84/Hour
- Electricity $31.39/Hour
- Media Replacement $0.89/Hour
- **Total $814.12/Hour**

The following are the operating costs for the oxy fuel furnace:

- Fuel $781.84/Hour
- Oxygen $995.28/Hour
- **Total $1777.12**

ENVIRONMENTAL CONSIDERATIONS

NOx and carbon dioxide are evaluated on a unit energy basis as is done throughout the United States. The NOx and carbon dioxide were considered not only from the actual operation of the furnace but also from the generation of electricity and the separation of oxygen. No consideration was given to any NOx and carbon dioxide generated by cryogenic processes. Again, all values consider the operation of the furnace at the rated throughput.

The following are the environmental considerations for the regenerative furnace:

- NOx from the Operation of the Furnace 0.08 lb/MMBTU
- NOx from Electrical Power Generation for Furnace Combustion 0.002 lb/MMBTU
- CO_2 from the Operation of the Furnace 118 lb/MMBTU
- CO_2 from Electrical Power Generation for Furnace Combustion 5.2 lb/MMBTU
- **Total NOx 0.082 lb/MMBTU**
- **Total CO_2 123.2 lb/MMBTU**

The following are the environmental considerations for the oxy fuel furnace:

- NOx from the Operation of the Furnace 0.04 lb/MMBTU
- NOx from Manufacture of Oxygen (Separation Only) 0.026 lb/MMBTU
- CO_2 from the Operation of the Furnace 118 lb/MMBTU
- CO_2 from Manufacture of Oxygen 65.03 lb/MMBTU
- **Total NOx 0.066 lb/MMBTU**
- **Total CO_2 183.03 lb/MMBTU**

CAPITAL COSTS

Capital Costs are evaluated based on equipment supply and major component supply. No consideration was given to installation, piping, or ancillary equipment such as recuperators.

The following are the capital costs for these combustion systems. The conventional combustion system is included as a reference .

- Regenerative Burners: $3,000,000
- Oxy Fuel Burners $480,000
- Conventional Burners: $1,200,000

HYBRID SYSTEMS

More often than not a complete regenerative or oxy fuel system is cost prohibitive as long as natural gas remains so inexpensive. In order for both regenerative and oxy fuel systems to become economically viable, combinations of conventional firing with regenerative or oxy fuel firing are much more popular. These systems range from limiting the zones of regenerative or oxy fuel firing as well as using by product fuels for regeneration and enriching the air stream with oxygen.

The following are specific cases being considered:

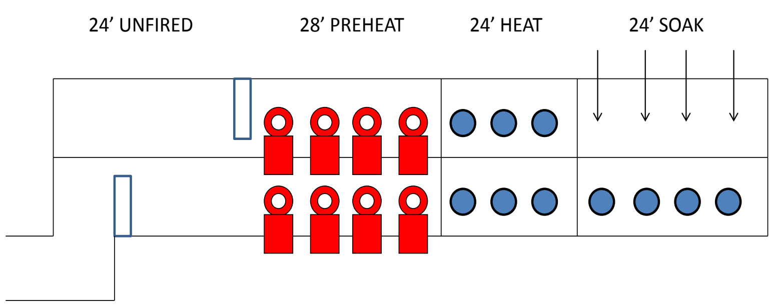
- Regenerative Preheat zones only
- Oxy Fuel Preheat Zones Only
- Dual Blast Furnace Gas Regenerative Burners in Preheat zone
- Oxygen Enrichment to 27% oxygen in the air stream

Regenerative Preheat Zones

By only firing the preheat zones regenenerativeły, the capital costs can be reduced while still saving some fuel. The preheat zones are chosen because they are the zones with the highest capacity and are the closest to the flue so that the work that the furnace gases do is maximized before some of the gases get regenerated. A hybrid furnace with an extra booster zone could also be presented to affect an increase in throughput but it is beyond the scope of this presentation.

The following is the typical furnace with regenerative preheat zones.

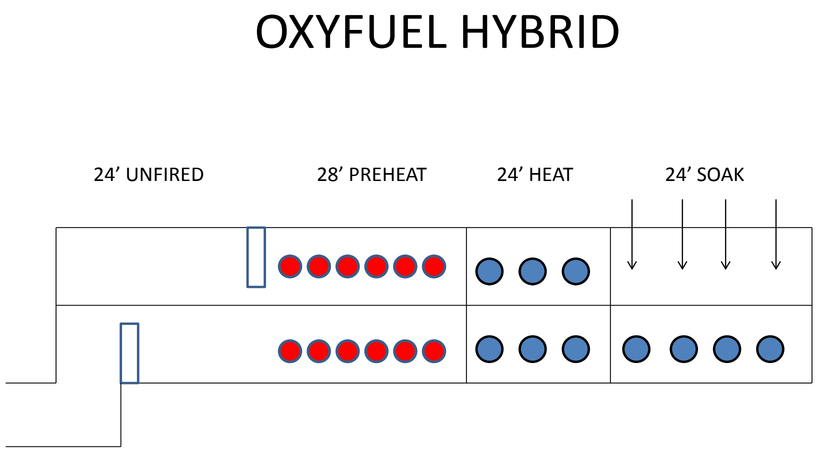
REGENERATIVE HYBRID



Oxy Fuel Hybrid

Preheat Zones are again chosen as the hybrid zone here as well using the same logic as that was used for the regenerative hybrid firing. Again, a furnace with an oxy fuel booster zone to affect an increase in throughput could be discussed here also.

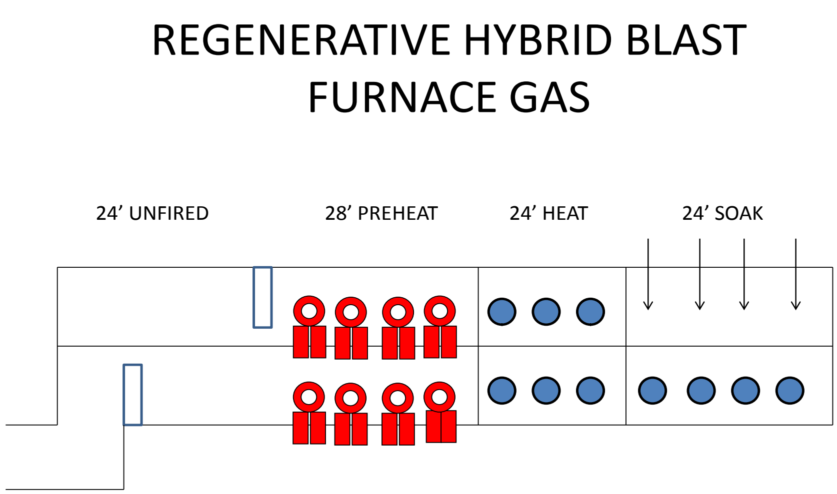
The following is the typical furnace with oxy fuel burners in the preheat zone:



Blast Furnace Gas Regeneration

The idea behind blast furnace gas regeneration is to utilize blast furnace gas in the preheat zones to reduce the amount of natural gas consumed. In order get the required efficiencies from the combustion both the fuel and combustion air should be regenerated using two separate media cases. Doing this, the high flame temperatures required for reheating can be attained.

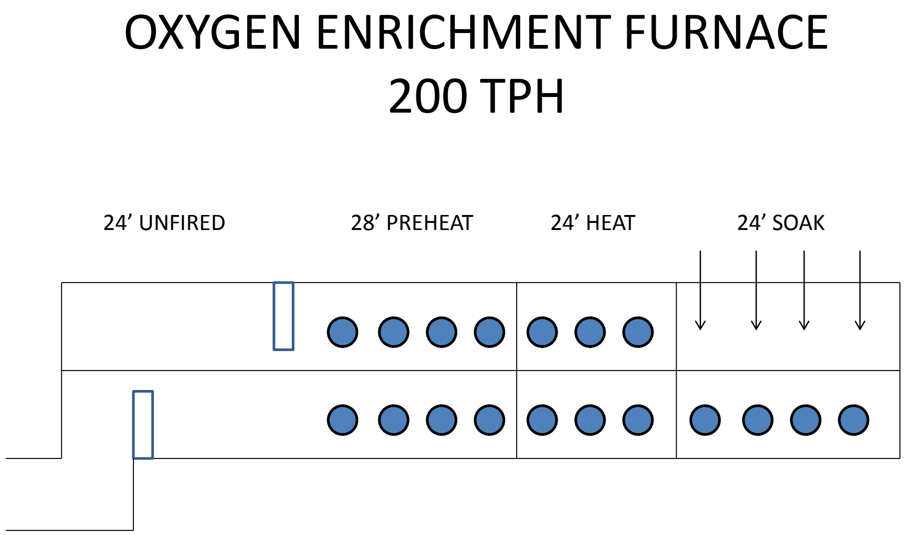
The following is the typical furnace with dual blast furnace gas regenerative burners in the preheat zones:



Oxygen Enrichment

Enriching the combustion air with oxygen reduces the stoichiometric combustion air ratio thus raising the combustion efficiency. Most burners can tolerate a nominal amount of oxygen enrichment, however they should be checked with the burner manufacturer for NOx liability before embarking on such a modification. For this example, enrichment to 27% oxygen is chosen because this is the maximum oxygen level that most low NOx burners can tolerate.

The following is the typical furnace with oxygen enrichment. It is the same as the base case since neither the burner nor the configuration will change dramatically.



The following is the fuel usage summary for the continuous furnaces discussed:

- Base Case: 1.245 MMBTU/Ton
- Regenerative Furnace: 1.049 MBTU/Ton
- Oxy Fuel Furnace: 1.054 MMBTU/Ton
- Regenerative Hybrid: 1.112 MMBTU/Ton
- Oxy Fuel Hybrid: 1.108 MMBTU/Ton
- Blast Furnace gas Regenerative: 1.275 MMBTU/Ton; 48% Natural Gas Reduction
- 27% Oxygen Enrichment: 1.115 MMBTU/Ton

Using the same criteria as previously presented, the following is the operating cost summary for the continuous furnaces discussed:

- Base Case: $826.41/Hour
- Regenerative Furnace: $814.12/Hour
- Oxy Fuel Furnace: $1777.12/Hour
- Regenerative Hybrid: $765.04/Hour
- Oxy Fuel Hybrid: $1095.38/Hour
- Blast Furnace Gas Regenerative: $475.03/Hour
- 27% Oxygen Enrichment: $1017.95/Hour

Since some of these cases have been run for different throughputs the following are the specific operating costs:

- Base Case: $4.13/Ton
- Regenerative Furnace: $3.70/Ton
- Oxy Fuel Furnace: $8.08/Ton
- Regenerative Hybrid: $3.82/Ton
- Oxy Fuel Hybrid: $5.48/Ton
- Blast Furnace Gas Regenerative: $2.38/Ton
- 27% Oxygen Enrichment: $5.09/Ton

The following are the environmental considerations for the continuous furnaces discussed:

- Base Case: 0.057 lb/MMBTU NOx; 121.0 lb/MMBTU CO_2
- Regenerative Furnace: 0.082 lb/MMBTU; 123.2 lb/MMBTU CO_2
- Oxy Fuel Furnace: 0.066 lb/MMBTU; 183.3 lb/MMBTU CO_2
- Regenerative Hybrid: 0.070 lb/MMBTU; 122.1 lb/MMBTU CO_2
- Oxy Fuel Hybrid: 0.064 lb/MMBTU; 147.2 lb/MMBTU CO_2
- Blast Furnace Gas Regenerative: 0.068 lb/MMBTU; 141.7 lb/MMBTU CO_2
- 27% Oxygen Enrichment: 0.060 lb/MMBTU; 137.6 lb/MMBTU CO_2

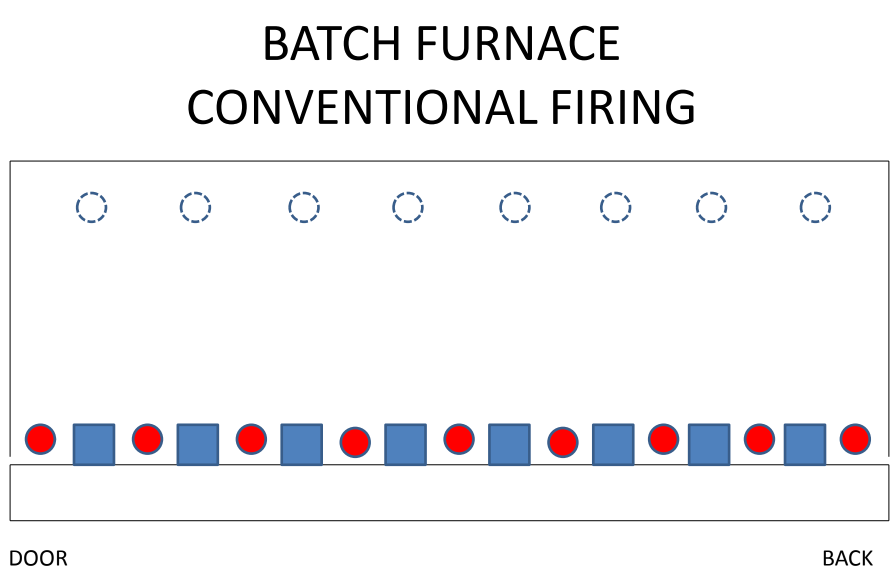
The following is a summary of the capital costs for the continuous furnaces discussed:

- Base Case: $1,200,000
- Regenerative Furnace: $3,000,000
- Oxy Fuel Furnace: $480,000
- Regenerative Hybrid: $2,200,000
- Oxy Fuel Hybrid: $1,150,000
- Blast Furnace Gas Regenerative: $2,800,000
- 27% Oxygen Enrichment: CASE DEPENDENT

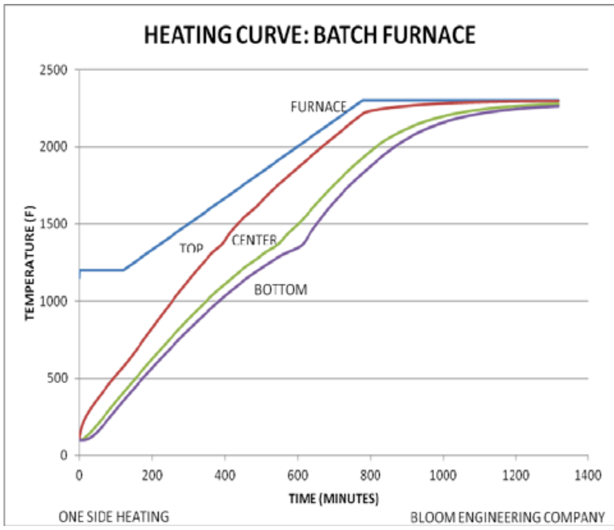
BATCH FURNACES

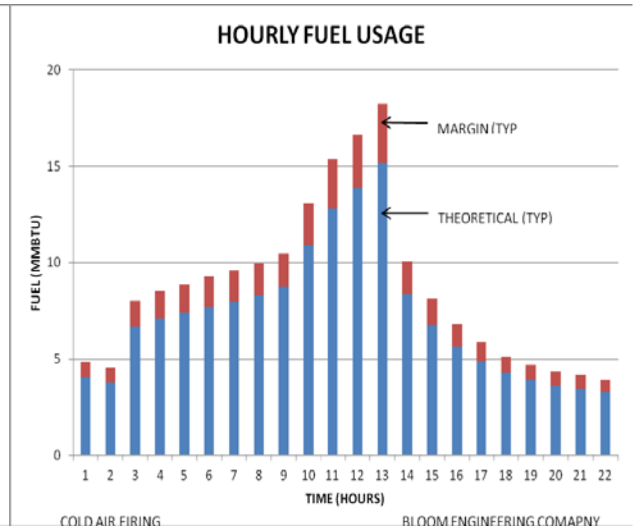
As before, a typical batch furnace will be evaluated for regenerative and oxy fuel firing. Here, however there is no need to evaluate hybrids since the furnaces are typically much smaller. A car bottom furnace is chosen here. The results generated from this particular furnace example do not imply any specific performance guarantee. The furnace is shown below. The following are the parameters for this furnace:

- 44 ton Load
- 8-20”X20”X194” Pieces
- Cold Air Firing
- Natural Gas Firing (1000BTU/SCF)



The following is the heating curve: The following is the associated fuel usage

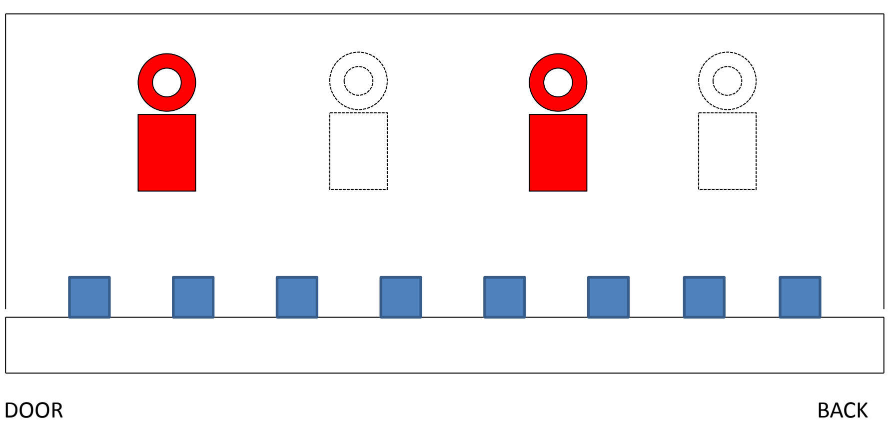




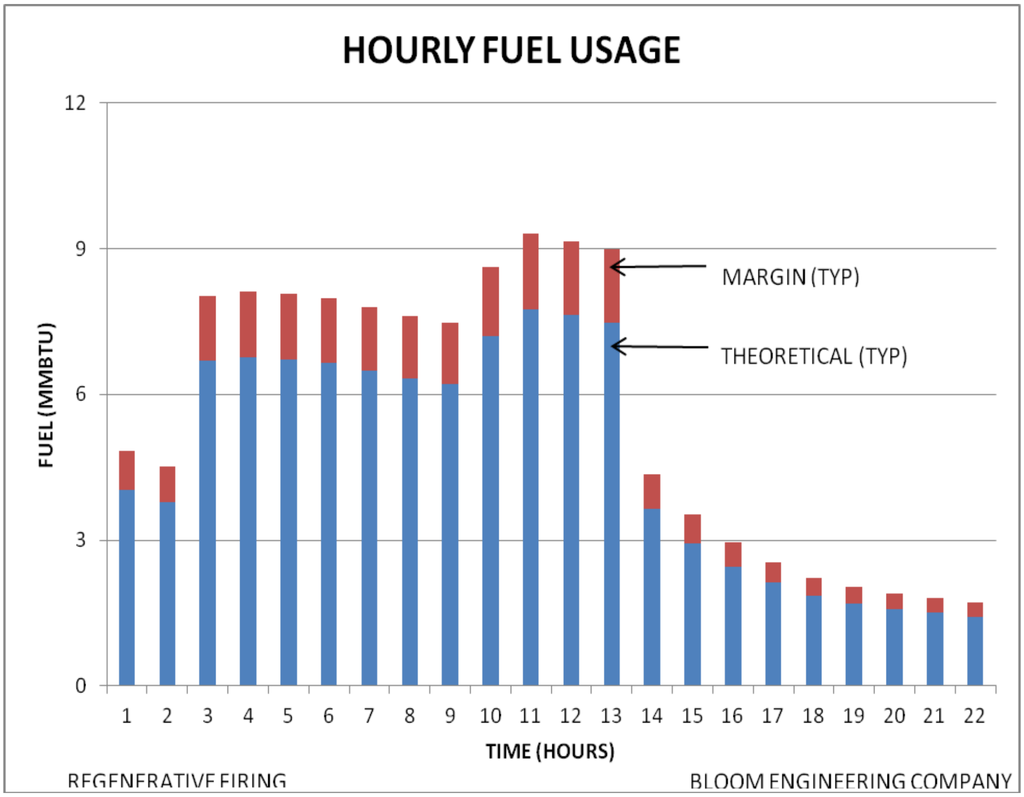
Regenerative Furnace

When regenerative burners are applied to this furnace the firing pattern will changed but the heating quality will remain the same. The regenerative batch furnace is presented below:

BATCH FURNACE
REGENERATIVE FIRING



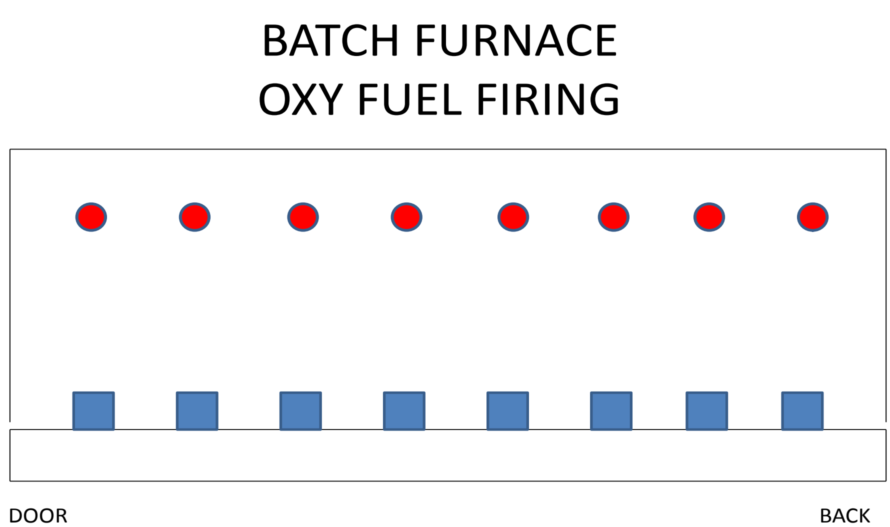
The following is the fuel distribution for the regenerative furnace:



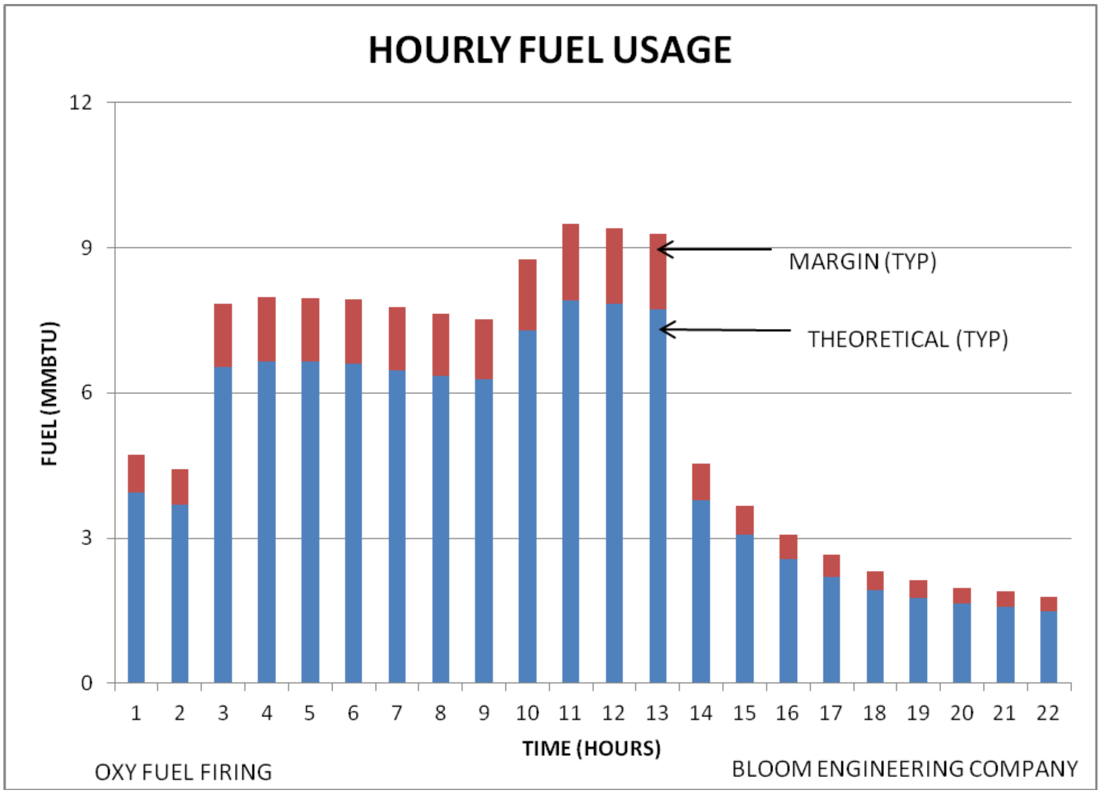
MAXIMUM FUEL USAGE: 7.63 MMBTU/Hr
AVERAGE FUEL USAGE: 4.68 MMBTU/Hr

Oxy Fuel Furnace

The oxy fuel batch furnace is top fired only to keep the oxygen fame away from the pieces. The oxy fuel batch furnace is presented below:



The following is the fuel distribution for the batch furnace:



MAXIMUM FUEL: 7.91 MMBTU/Hr
AVERAGE FUEL: 4.73 MMBTU/Hr

OPERATING COSTS

The following is the basis for determining the utility costs:

- Fuel Cost \$3.37/1000 SCF
- Electricity \$0.075/KWH
- Oxygen \$0.20/100 SCF
- Total Fuel 4.73 MMBTU/Hr Both Case
- 30 Operating Horsepower for Regenerative Fans
- Total Oxygen 10,170 SCF

The following is the fuel summary for the batch furnaces:

- Cold Air Firing: 158.73 MMBTU; 3.607 MMBTU/Ton
- Regenerative Firing: 102.95 MMBTU; 2.340 MMBTU/Ton
- Oxy Fuel Firing: 103.96 MMBTU; 2.363 MMBTU/Ton

The following are the operating costs for the regenerative furnace:

- Fuel: $15.94/Hour
- Electricity: $1.68/Hour
- Media Replacement $0.03/Hour
- **Total $17.65/Hour**

The following are the operating costs for the oxy fuel furnace:

- Fuel $15.94/Hour
- Oxygen $20.34/Hour
- **Total $36.28/Hour**

ENVIRONMENTAL CONSIDERATIONS

The environmental considerations will be evaluated in the same manner as was done for the continuous furnaces.

The following are the environmental considerations for the regenerative batch furnace:

- NOx from the Operation of the Furnace 0.08 lb/MMBTU
- NOx from Electrical Power Generation for Furnace Combustion 0.002 lb/MMBTU
- CO_2 from the Operation of the Furnace 118 lb/MMBTU
- CO_2 from Electrical Power Generation for Furnace Combustion 5.2 lb/MMBTU
- **Total NOx 0.082 lb/MMBTU**
- **Total CO_2 123.2 lb/MMBTU**

The following are the environmental considerations for the oxy fuel batch furnace:

- NOx from the Operation of the Furnace 0.04 lb/MMBTU
- NOx from Manufacture of Oxygen (Separation Only) 0.026 lb/MMBTU
- CO_2 from the Operation of the Furnace 118 lb/MMBTU
- CO_2 from Manufacture of Oxygen 65.03 lb/MMBTU
- **Total NOx 0.066 lb/MMBTU**

- **Total CO_2 183.03 lb/MMBTU**

CAPITAL COSTS

Capital Costs are evaluated based on equipment supply and major component supply. No consideration was given to installation, piping, or ancillary equipment such as recuperators.

The following are the capital costs for these combustion systems. The conventional combustion system is included as a reference .

- Regenerative Burners: $375,000
- Oxy Fuel Burners $50,000
- Conventional Burners: $100,000

CONCLUDING REMARKS

The capital cost of the regenerative burner is quite high while the operating costs of the oxy fuel burner are quite high as well. There are potential maintenance issues associated with regenerative burners while there are potential safety issues associated with oxy fuel burners. The fuel and environmental issues on both firing systems are acceptable.

Both the regenerative and oxy fuel systems may be impractical as complete systems but a hybrid furnace may be more feasible for both systems of combustion.

There is a next generation regenerative burner set to be released in 2013 that will reduce the NOx generation of regenerative burners to lower values than stated in this paper.

References

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