Regenerative Burners- Are They Worth It?

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Abstract

Regenerative burner systems for high temperature furnaces in the Steel, Aluminum and related industries have now been on the market for over 20 years. Despite the dramatic potential gains in fuel efficiency and furnace productivity, industry acceptance remains relatively slow. Of particular current interest is the potential for reduction of CO2 emissions through the use of these systems.

Plant personnel are often reluctant to pursue the installation of Regenerative systems, for a variety of reasons. Often they cite high initial costs and perceived additional maintenance as the reasons for declining to install such systems. However, it can be shown that in many instances, the initial investment can be recovered in relatively short times and the ongoing fuel savings vastly outweighs the added maintenance costs. Some guidelines will be presented to assist in identifying the most promising target applications.

This paper will review the performance capabilities of currently available burner systems and then discuss the practical implications associated with their use. Examples of various successful furnace applications as well as experience with alternate fuels will be presented.

Scope of this paper

The following is intended to provide a general discussion of the current state of the art in commercially available periodic-type (flow reversal) Regenerative burner systems utilizing ceramic heat storage media. Furthermore, the discussion primarily covers applications to high temperature furnaces, defined as furnaces with operating temperatures in the approximate range of 1000 to 1400^{o}C.

Introduction

Regenerative burner systems have been commercially available for high temperature heating furnaces for about 20 years. There are in excess of 100 furnaces in the North America equipped with Regenerative combustion systems of various types. Despite the proven benefits of ultra high fuel efficiency and high productivity, many other plants remain reluctant to adopt this technology.

The chief reasons for avoiding Regenerative technology have been high NO_X emissions, excessive maintenance and initial cost. For example, some early systems had NO_X emissions well in excess of 840 ppmv @ $3\%O_2$ (1.0 lb/MM BTU-HHV). Most new projects now require emissions of 84 ppmv @ $3\%O_2$ (0.1 lb/MM BTU-HHV) or less. Several years ago, exhaust gas recirculation (EGR) systems were developed which achieved acceptable NO_X values, but resulted in additional costs, maintenance and efficiency penalties. Maintenance costs for Regenerative burners and heat-exchange media have in some cases substantially offset the fuel savings.

Finally, higher initial equipment costs have caused some users to avoid Regenerative systems, despite the typical 50-60% fuel savings available. Recent large increases in the cost of energy in North America has lead to an increased interest level in high efficiency combustion systems, and has significantly improved the payback times for such equipment. For example, a typical cold-air aluminum melting furnace can often be converted to Regenerative firing with a net payback time of well under one year, with all factors such as installation and maintenance factored in.

Although the cycling Regenerative-type burner is now rather well known, a simplified schematic diagram is provided for reference. Most manufacturers are designing their systems for reversal times in the range of about 20 seconds to 120 seconds. The shortest cycle times can allow minimized heat storage bed size and improved temperature uniformity, while longer times reduce the amount of wear and tear on the cycling components.

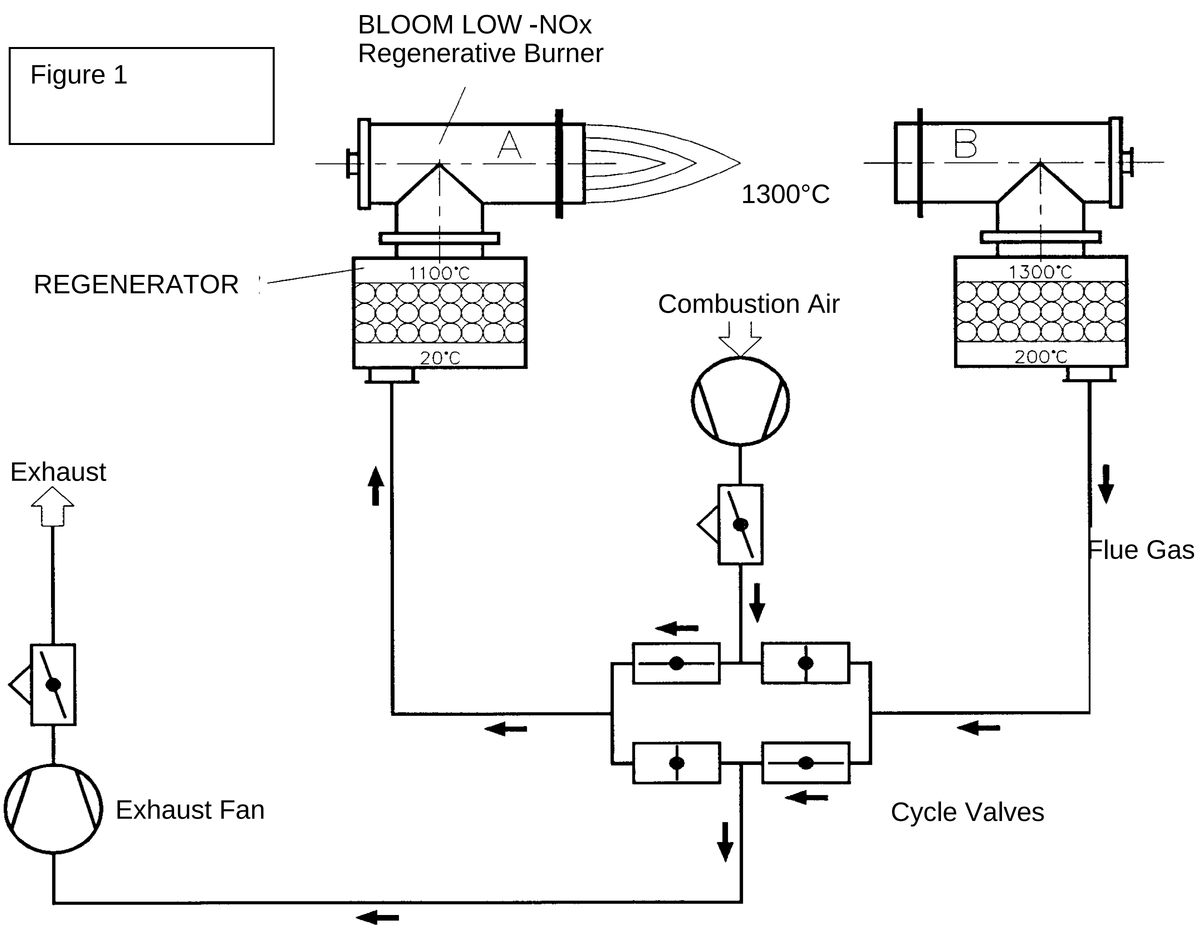
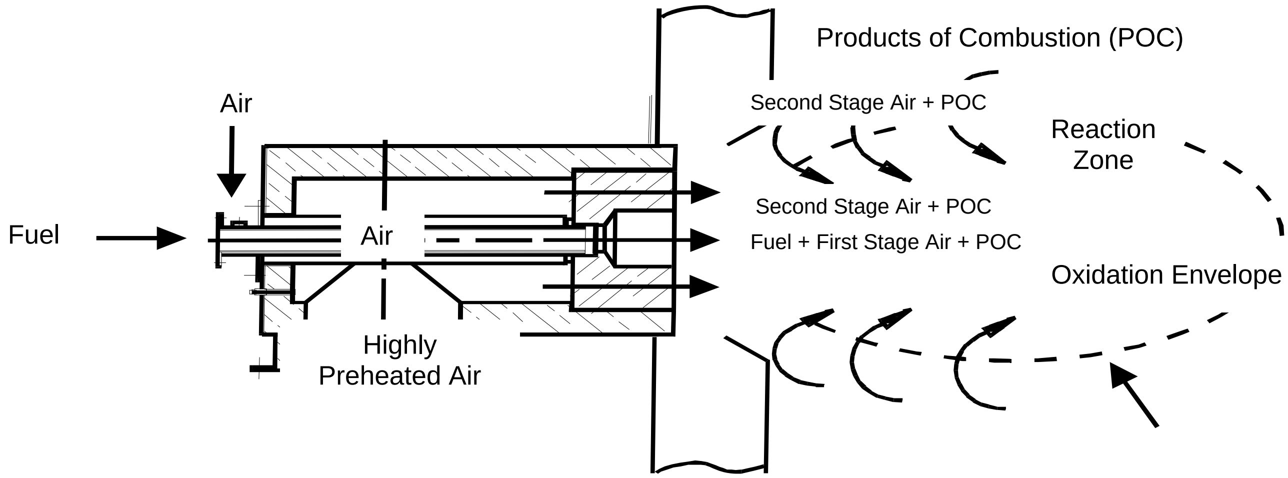


Figure 1

Bloom Engineering conducted a research and development effort in order to address the problem of high NO_X emissions from Regenerative burners. The Bloom LumiFlame™ burner design shown conceptually in Figure 2 provides an example of an Ultra Low NOx burner.

Figure 2 LumiFlame Ultra Low NO_X Concept



The concept of internal furnace POC (products of combustion) recirculation into the root of the flame for NO_X reduction is well known. However, until recently the NO_X levels achieved using this technique with Regenerative air preheat levels remained excessive. EGR was therefore required in most cases. Bloom employed its R&D facilities in a combination of laboratory-scale burner testing and Computational Fluid Dynamics (CFD) modeling to study the problem and optimize burner design and performance. CFD was also utilized to study the impact of burner design on flame heat transfer characteristics, to insure that the resulting designs would produce flames suitable for aluminum melting applications.

Key Design Characteristics of the LumiFlame Burner Include:

1) A simple, rugged high alumina “baffle” which is used to create the necessary air and fuel flow jet patterns for ultra low NO_X emissions, as well as providing support for the fuel nozzle and shielding the burner internals from furnace radiation.

2) “First stage” air port, used to provide stable operation at furnace temperatures below 980°C. Air is fed to this port to provide cold start and low temperature batch furnace modes, while still achieving extremely low NO_X and good efficiency. Figure 3 illustrates the efficiency of LumiFlame Regenerative burners compared with cold air combustion.

3) Unique High Luminosity/High Heat Transfer flames on gas or fuel oil operation.

4) Adjustable directivity, to optimize the flame for various furnace types. For example, flames can be directed toward the aluminum bath of a sidewell melter, without the problem of excessive burner velocity (which can lead to excessive dross formation by constantly exposing fresh metal). The luminous, medium velocity flame pattern is similar to previous versions of Bloom melting furnace burners.

5) The oxidizing medium (in this case high-preheated air) shrouds the fuel, such that contact between reducing atmosphere gases and product to be heated is minimized.

6) Exhaust Gas Recirculation equipment is not employed. Essentially, the “vitiation” effect of EGR is accomplished using the internal burner/port geometry.

The widespread adoption of PLC control systems is making it easier than ever for plants to install and maintain the type of controls needed for Regenerative burner systems. PID loop control, cycle-valve switching, alarming, trending, start-up/shutdown and trouble-shooting functions can now be incorporated into PLC/HMI equipment. The number and type of devices, which the electrical maintenance personnel must handle, is significantly reduced versus earlier systems.

In addition to the Ultra Low NO_X burner development program, Bloom has addressed other major drawbacks of previous Regenerative burner systems as well. For aluminum melter applications with salt fluxing, the Bloom Regenerative media beds can be provided with either a hinged easy-open cleanout door or completely removable media case (with compression-type, no-bolt, quick connector option). In either case, a spare amount of media on hand allows quick replacement and minimal burner downtime. The contaminated media is then cleaned off-line and can be reused many times.

Our maintenance history experience shows that concerns about high maintenance costs are unfounded (for direct-fired Regenerative systems). Spare parts for maintenance have typically averaged only about 2-4% of system initial cost per year, covering all burner and cycle valve hardware.

Performance

As shown in Figures 3 and 4, the Bloom LumiFlame concept employing High Internal POC Recirculation produces extremely low NO_X emissions, while maintaining high combustion efficiency.

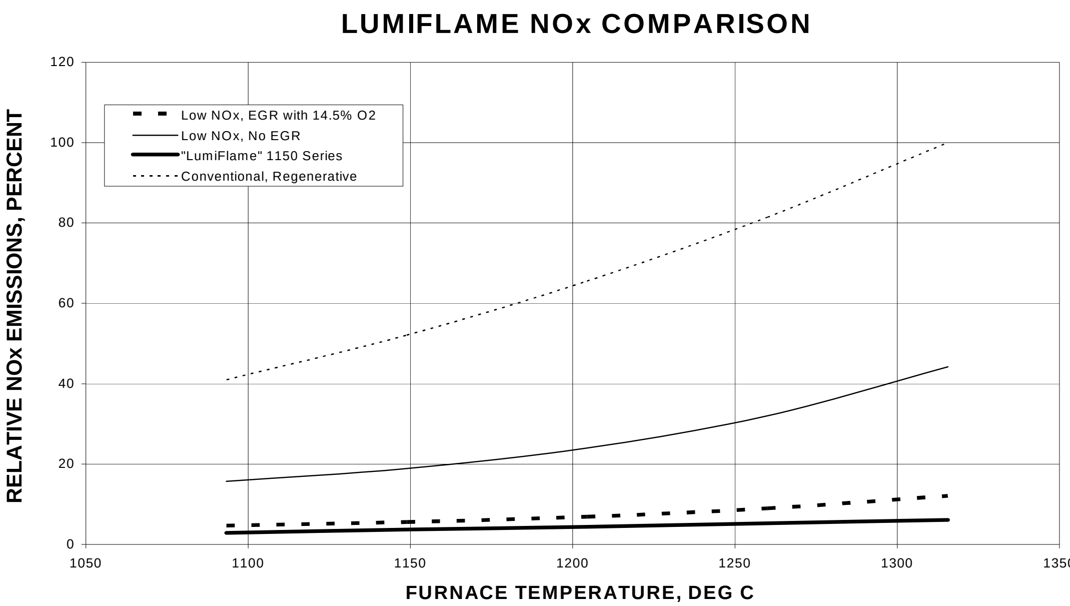


Figure 3

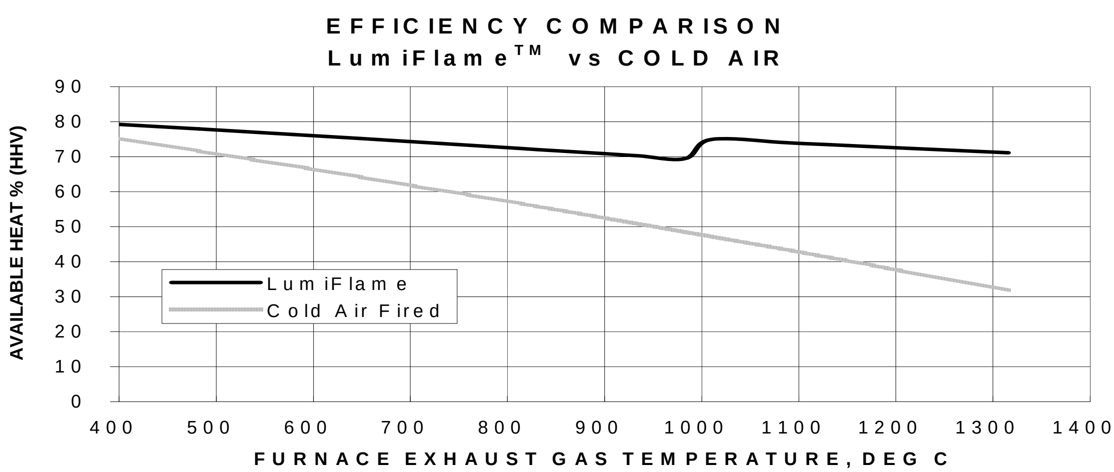


Figure 4

Other “Low NO_X technologies” such as oxy-fuel or POC post-treatment have significant practical drawbacks in aluminum melter applications. For example, while pure O_2/CH_4 mixtures would produce zero NO_X emissions, nitrogen (N_2) will enter the process via the fuel, as well as tramp air into the furnace chamber in most real-world systems. Furthermore, the cost for oxygen must be factored in to any comparison with Regenerative firing. Table 1 illustrates that oxy-fuel operating costs are more than double those of Regenerative systems.

Operating Cost Comparison Per Hour For 10 MM BTU/hr
(2.52 x 10^6 Kcal/hr) Net Heat Input to Furnace

	Cold Air	Recuperative 500°C Preheat	Regenerative	Oxy Fuel
Equivalent Burner Input (10^6Kcal/Hr)	8.09	5.27	3.54	3.54
Natural Gas (NM^3)	909	594	399	399
Fuel Cost ($)	192.40	125.80	84.40	84.40
Oxygen (NM^3)	-	-	-	913
Oxygen Cost ($)	-	-	-	80.52
Electrical Cost for Blowers ($)	1.97	2.67	2.74	-
Total Cost/Hr ($)	194.37	128.47	87.14	164.92

Table 1

Basis:

- Efficiencies calculated on furnace exhaust gas temperature of 1300°C
- Fuel Cost $6.0/MM BTU
- Oxygen Cost $0.25/ccf (liquid oxygen)
- Electricity Cost $0.075/kWh

Since oxygen production itself consumes substantial energy, the cost comparison results are unlikely to change for the foreseeable future. The net environmental ‘benefit’ of reduced CO2 and NOx reduction is also questionable when the electric power generation required for oxygen production is factored in.

Catalytic or other post-treatment systems typically require specific reaction temperature windows, which are difficult to achieve continuously on process furnaces such as aluminum melters. We are currently unaware of any domestic industrial melting furnaces utilizing a post-treatment NO_X suppression system for the POC gases.

Carbon monoxide (CO) emissions from a properly tuned conventional combustion system are generally below 50 ppmv (corrected to 3% O2). Field data from several installations have confirmed that the Bloom LumiFlame system produces significantly less than 50 ppmv even at low excess air levels.

Carbon dioxide (CO_2) is emitted in direct proportion to the amount of fuel consumed for hydrocarbon fuels. Since Regenerative firing results in the highest available combustion efficiencies, CO_2 emissions are dramatically reduced, as illustrated in Table 2:

Efficiency and CO_2 Emissions
Basis: 1300°C Furnace Exhaust Gas Temperature, Natural Gas Fuel

Type of System	Air Preheat Temp °C	% Available Heat-HHV	kg CO_2 Emitted per kcal x 10^6 Net to Process
Cold Air	21	32	675
Recuperative	500	49	440
Regenerative	1130	71	300

Table 2

Another area of advantage for Regenerative systems on aluminum melting furnaces is that the regenerator media acts as a filter of POC particulates, such as salt fines and dross particles. By filtering and returning much of this material to the furnace, particulate emissions are significantly reduced compared to conventional burner systems. Furthermore, the POC exhaust volume and temperature is much lower than conventional systems, so that in the event that baghouse collection were required, its size would be only a fraction of that needed when using cold air or recuperative systems. For retrofit situations in which a production increase is desired, Regenerative burners are often an attractive alternative to enlargement of the exhaust ducting and flue system.

Applications

Aluminum Melting

Scrap remelting and recycling furnaces are generally good candidates for Regenerative combustion systems. The economics of applying Regenerative burners should be evaluated when planning new furnaces or modifications to existing combustion systems. Productivity increases can often be achieved via the proper application of Regenerative burners. The LumiFlame system has been proven to provide excellent melt rates while maintaining its low NO_X emissions over a wide range of design chamber temperatures. Specific fuel rates with Regenerative systems typically are below 1000 BTU/lb-HHV (505 kcal/kg-LHV). Proper attention to burner placement is key to achieving the desired melt rate and efficiency goals. CFD studies can be a useful tool for this evaluation, as illustrated in figure 5.

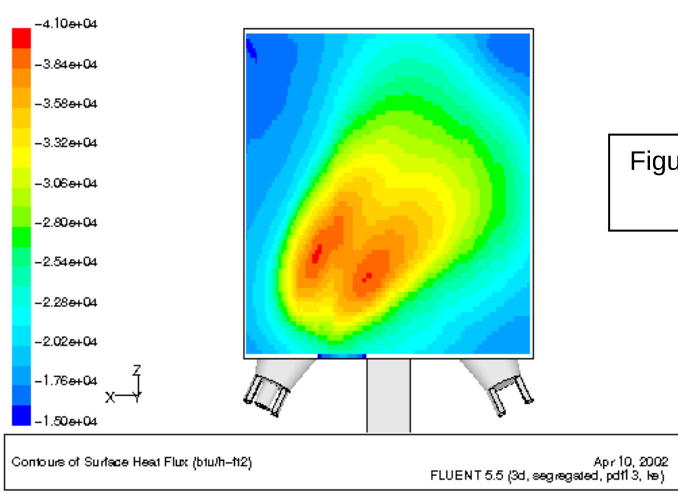


Figure 5

As we have seen, the recent advances in Ultra Low NO_X Regenerative Burner Systems have eliminated or reduced nearly all of the perceived drawbacks for aluminum melter applications. The initial system costs can be quickly recovered in most cases due to reduced operating (fuel) costs, and the environmental benefits provide further justification for this technology.

Continuous Steel Reheating Furnaces

Regenerative burners require a unique set of application guidelines. A Regeneratively fired furnace is designed and operated significantly different than a conventionally fired hot air furnace. That said, given the proper application, a Regenerative furnace can be a highly efficient, very reliable alternative to conventional combustion.

Regenerative burners are typically installed for side firing. The Regenerative processes of reversing combustion, is ideally suited for side wall firing, and results in excellent uniformity across the width of the furnace. Spacing of the burners along the side walls should be addressed particularly in bottom zones of walking beam furnaces. Great care should be taken to place the burners in open firing aisles, to prevent flame disruption which can cause increase in NOx production, as well as physical damage to the skid system. Examples of burner placement studies and resulting expected uniformity are shown in figures 6 and 7.

Burner control typically limits burner turndown to approximately 25 – 30% capacity to prevent flame lift, as well as maintaining proper temperature distribution across the furnace width. With the PLC control, burners can be “cascaded” on and off to optimize furnace efficiency and minimize NOx production.

Regenerative side firing on a steel slab heating furnace

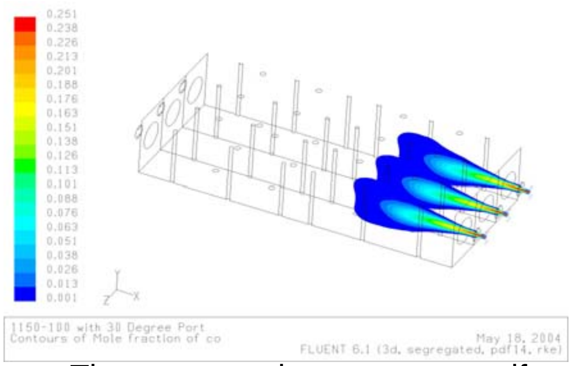


Figure 6

Time-averaged temperature uniformity (CFD model)

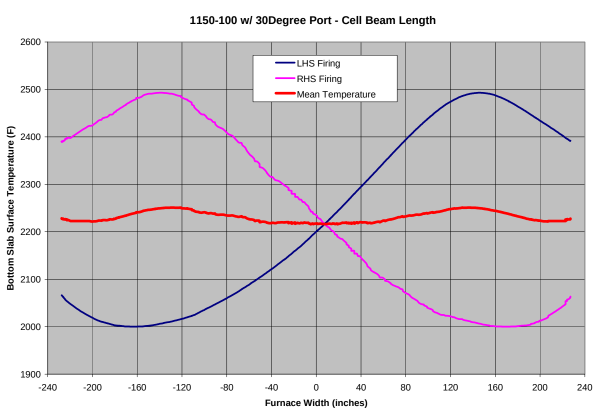


Figure 7

Fuel consumption of about 1.0 mmBTU/Short ton-HHV (0.25 kcal/mton LHV) on cold-charged product is achievable with Regenerative firing. Admittedly it is possible to build a ‘conventional’ continuous reheat furnace which can approach this level, but this requires a significantly longer furnace and high-performance recuperator. In many cases the Regenerative option is cost-competitive and can provide higher productivity for a given furnace length. For the same reasons, Regenerative ‘booster’ zones can be an attractive option for increasing the productivity while improving the efficiency of existing furnaces.

The LumiFlame system can operate with a variety of typical steel mill fuels, including coke oven gas, mixed COG/BFG, light and heavy fuel oils, while achieving excellent low-emission performance.

Batch-type steel heating furnaces

Forging and other high-temperature heating processes can achieve dramatic efficiency gains by switching to Regenerative burners. Often the batch-type furnace will have a flue gas temperature exceeding 1200 C. As seen in figure 3, this would result in a fuel savings of 47% compared with cold-air firing. The added equipment cost may be partially offset because of the temperature uniformity benefits of the cyclic Regenerative firing, thus allowing a reduction in the number of burners required. The results of a recent CFD study illustrate in figure 9 how burner placement can be optimized on a batch-type soaking pit used for specialty steel forging.

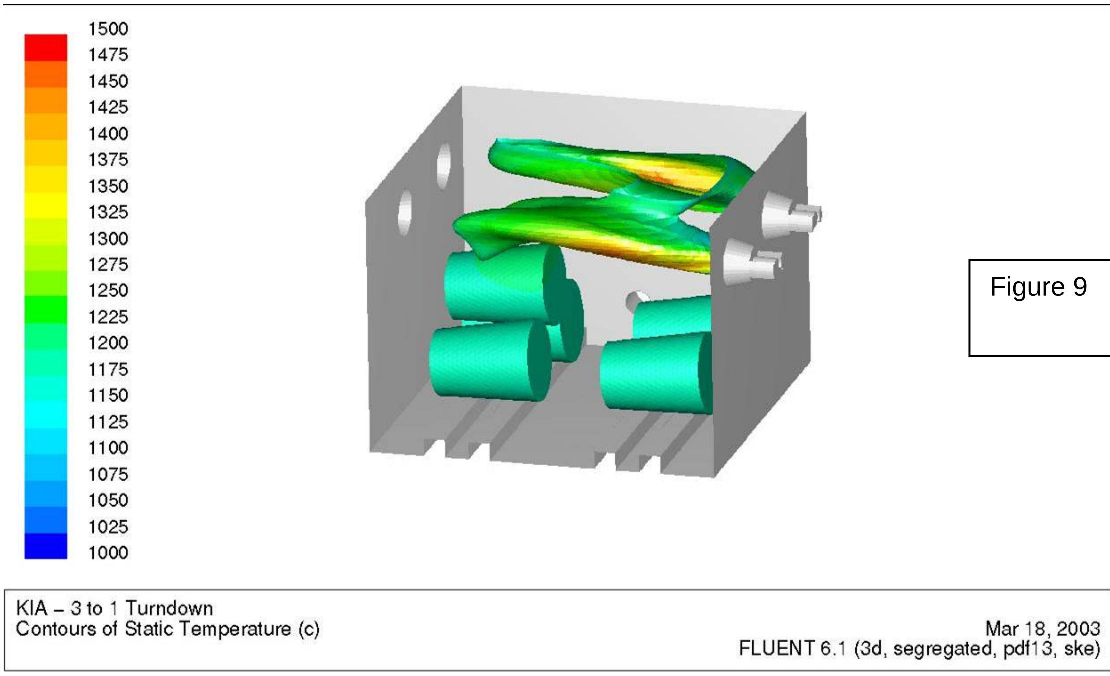


Figure 9

Specialty Indirect-type Heating

Indirect heating, in which the products of combustion do not come in contact with the product is used in numerous industrial processes, such as steel strip heating (continuous or batch), tube heat-treating, galvanizing and specialty glass melting. The combustion can occur in radiant tubes or in a combustion chamber surrounding a muffle or crucible containing the product being heated. Such processes are often thermally inefficient due to the difficulty in obtaining high heat-transfer rates. Regenerative burners have been applied to decrease the energy required for such processes. The economics of any particular application depend on the process operating parameters. We would recommend that Regenerative burners be considered for applications in which the exhaust gas temperature exceeds about 900 ^{o}C.

Conclusion

Modern Regenerative combustion systems have been successfully applied in hundreds of applications around the world on a wide variety of industrial heating processes. The efficiency and environmental benefits are well-documented, and the maintenance concerns and other perceived drawbacks have been largely overcome with the latest available system designs. With economic payback times often in the range of 1-2 years based on fuel savings, we believe that Regenerative combustion systems should be the design of choice for a wide variety of high temperature industrial heating processes. So, in many cases the clear answer is YES, Regenerative burners are ‘Worth It’.