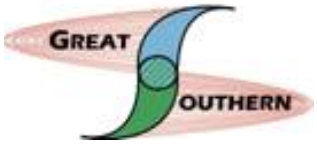

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FLAMELESS HEATER PERFORMANCE
TWO YEARS OF OPERATION

Authors:
William C. Gibson – President
Marianne Zimola – Sr. Process Engineer-Advanced Technologies
Great Southern Flameless, LLC
2700 N. Hemlock Ct., Suite 100
Broken Arrow, OK 74012
bill.gibson@greatsoutherngroup.com
marianne.zimola@greatsoutherngroup.com

ABSTRACT

The flameless crude heater designed by Great Southern Flameless (GSF) has been operating continuously since March 15, 2013.

During this 2 year run length (2.5 years by the time this paper is presented), GSF has spent many hours collecting and analyzing performance data. The conclusions of this analysis will be presented in the GSF paper with documentation to support the conclusions.

What is certain is that traditional rules of thumb for designing conventional refinery heaters must be rewritten for flameless heaters.

We will cover in detail the following:

1) NOx emissions equal to or lower than NOx emissions with traditional combustion plus an SCR system.
2) Equalization of peak to average radiant flux rates. API 530 ratios do not apply to flameless heaters with double fired radiant coils.
3) Tangential firing with associated significant increase in radiant section flue gas mass circulation.

4) Elimination of any possibility for hot flue gas or flame impingement on the radiant process coil.
5) Significant increase in run length and coil life by eliminating hot flue gas or flame impingement.
6) Significant reduction in the overall heater size.
7) Significant reduction in the process coil surface area.
8) Significant increase in traditional radiant section thermal efficiency.
9) Significant shift in duty load from the convection section to the radiant section.
10) Elimination of the requirement for filter/coalescer.
11) Improved safety and reliability (availability) when compared to traditional combustion with varying refinery fuel gas composition.
12) Scale up to any heater size while maintaining symmetry of combustion and heat flux to the double fired coil from the bottom to the top of the radiant section.
13) Significant reduction in price when compared to a traditional double fired heater with air preheat system.
14) Ever greater reduction in price when compared to a traditional double fired heater with air preheat and SCR system.

Great Southern Flameless has presented to the AFRC and IFRF numerous papers since 2009 detailing the projected and actual NOx reduction associated with GSF flameless combustion. This paper will document the significant improvement in all other areas of heater performance, operation and pricing.

TECHNICAL PAPER

Now that the flameless heater has been in continuous service for well over 2 years GSF is able to provide compelling performance data which shows proven benefits of flameless combustion technology for refinery process heaters.

NOx EMISSIONS

NOx reduction is the most obvious benefit of this technology. The flameless heater continuously produces SCR level NOx emissions but without an SCR. Table 1 shows Continuous Emission Monitoring System (CEMS) readings taken over a 4 month run period. Note that 8 ppmvd is equal to 0.01lb/MMBtu (HHV). The flameless heater emissions are consistently below 8 ppmvd.

TABLE 1 – CEMS Data Recorded Over a 4-Month Period

Date	NOx, lb/MMBtu (HHV)
7/14/2014 16:58	0.0064
6/30/2014 16:58	0.0066
6/12/2014 8:58	0.0078
5/30/2014 0:58	0.0069
5/14/2014 8:58	0.0066
4/27/2014 8:58	0.0073
4/13/2014 16:58	0.0066
3/31/2014 8:58	0.0079
3/18/2014	0.007
3/11/2014 16:58	0.0079

RADIANT HEAT FLUX

The flameless heater defies the current API 530 document which specifies that a 1.2:1 peak to average circumferential radiant heat flux is typical for a double fired coil. A GSF flameless heater will always be a double fired coil but the peak to average flux for the flameless heater is 1.0:1.0, therefore the API 530 circumferential factor is in error for a double fired flameless heater. While API 530 does not specify a longitudinal factor, it is commonly agreed to be between 1.1:1 and 1.4:1. The ratio for the GSF double fired coil with tangential firing is 1.0:1.0.

By equalizing the radiant heat flux, localized hot spots on the process coil are eliminated. Of course the length and surface area of the process coil is significantly reduced by the 1.0:1.0 peak to average circumferential and longitudinal ratios.

RADIANT SECTION FLUE GAS RECIRCULATION

Another unique feature of the flameless heater is the radiant section flue gas recirculation zone. CFD modeling has revealed that the radiant section flue gas recirculation rate is more than four times greater than a conventional heater. This high rate of flue gas recirculation is due to the tangential firing configuration and the high momentum imparted by the fuel and air nozzles. The recirculation zone is the area between the tube face of the process coil and the refractory walls of the heater. The flue gas velocity in the non-recirculation zone is typical of conventional radiant section velocities of 3-6 ft/sec.

FLAME/HOT GAS IMPINGEMENT

Hot gas or flame impingement cannot occur with the flameless heater technology due to several features:

1) Patented castable refractory dimple pattern on the interior radiant walls. The patented dimple pattern shown in Figure 1 is used to help pin the recirculating flue gas to the wall and keep it from impinging on the radiant coil.

2) The recirculation zone between the coil and the refractory is properly designed for the high volume of flue gas in circulation, ie. ample space is provided to ensure that hot recirculating flue gasses do not contact the process coil.

FIGURE 1

EXTENDED RUN LENGTH

Most heater shutdowns for cleaning the radiant coil are the result of localized high flux rates and high fouling rates. The localized high flux rates are caused by flame or hot gas impingement on the process coil. This issue is eliminated with the GSF flameless heater technology and thereby allows for extended run length.

Avoiding unnecessary shut downs is important for both safety and economics. Most heater incidents occur during start-up or shut down so it is always preferable to have the heater in continuous operation for the longest run length possible.

REDUCED HEATER SIZE

There is a capital cost benefit of the GSF flameless design as well. The flameless heater allows for a reduction in heater size due to the longitudinal/circumferential factor and much higher average radiant section flux rates without exceeding allowable peak radiant section flux rates. Table 2 below illustrates the difference in flux rates between a conventional heater and the GSF flameless heater.

TABLE 2

	Average Radiant Flux	Peak to Average Flux Ratio (Circumferential Factor)	API 530 Peak	Longitudinal Factor	Overall Peak Flux Rate
Traditional Single Fired Heater	10,000	1.8 (S.F.)	18,000	1.33	24,000
GSF Flameless Double Fired Coil	21,000	1.0	21,000	1.0	21,000

RADIANT COIL SURFACE AREA

The economic result of this equalized high flux rate is a 52% reduction in required process coil surface area which equates to a 52% reduction in coil capital cost. Additionally, the reduced coil length means the coil pressure drop is reduced and the mass velocities can be increased without exceeding allowable pressure drop. Higher mass velocities are important for processing shale oil or any thermally sensitive process fluid.

RADIANT SECTION DUTY AND EFFICIENCY

A typical radiant to convection section duty split for a conventional heater is 65% radiant duty and 35% convection duty. The GSF flameless heater is nearly all radiant resulting from the significantly higher radiant efficiency. Radiant efficiencies as documented in the GSF flameless heater have never been seen before in the refinery process heater industry. Flue gas temperature leaving the radiant section is approximately 1210^{o}F and the flue gas temperature leaving the convection section is approximately 1050^{o}F.

In summary, the radiant duty is 94.9% of the total process duty.

The radiant bridgewall temperature is reduced from the normal 1500-1600^{o}F range to the 1200^{o}F range. This 11% increase in radiant efficiency is achieved with much higher average radiant flux rates. But, due to the even flux rates throughout the radiant section, the peak flux rates are less than those associated with conventional combustion heat transfer.

ELIMINATION OF FILTER/COALESCER

Additional cost savings are realized due to the elimination of needing a fuel filter/ coalescer. The fuel nozzle port size is roughly 3/8" in diameter (Figure 2) which eliminates tip plugging issues which is common with ultra-low NOx burner tips. Ultra-low NOx burner tip drillings commonly have as small as 1/16" ignition ports which are prone to plugging with typical refinery fuel gas compositions.

FIGURE 2 - LARGE FUEL PORTS

It is frequently recommended that filter/coalescers be added to the fuel supply system whenever ultra-low NOx burners are utilized in order to reduce problems with burner stability and reduce frequency of tip cleaning maintenance. A filter/coalesce is not required with the GSF flameless heater design.

RELIABILITY (AVAILABILITY)

As of July 15th, 2015 the GSF flameless heater has been in operation for 2 years and 3 months without experiencing any loss of combustion (alarms or trips) in either the flameless or conventional firing modes. This has been well documented with the instrumentation package that is installed on the flameless heater. There are three different systems being monitored by the BMS which would indicate loss of combustion: 1) the downstream thermocouples are measuring temperature rate of change which would indicate loss of combustion, 2) there is a high CO DCS alarm and 3) there is also a high unburned hydrocarbon shutdown.

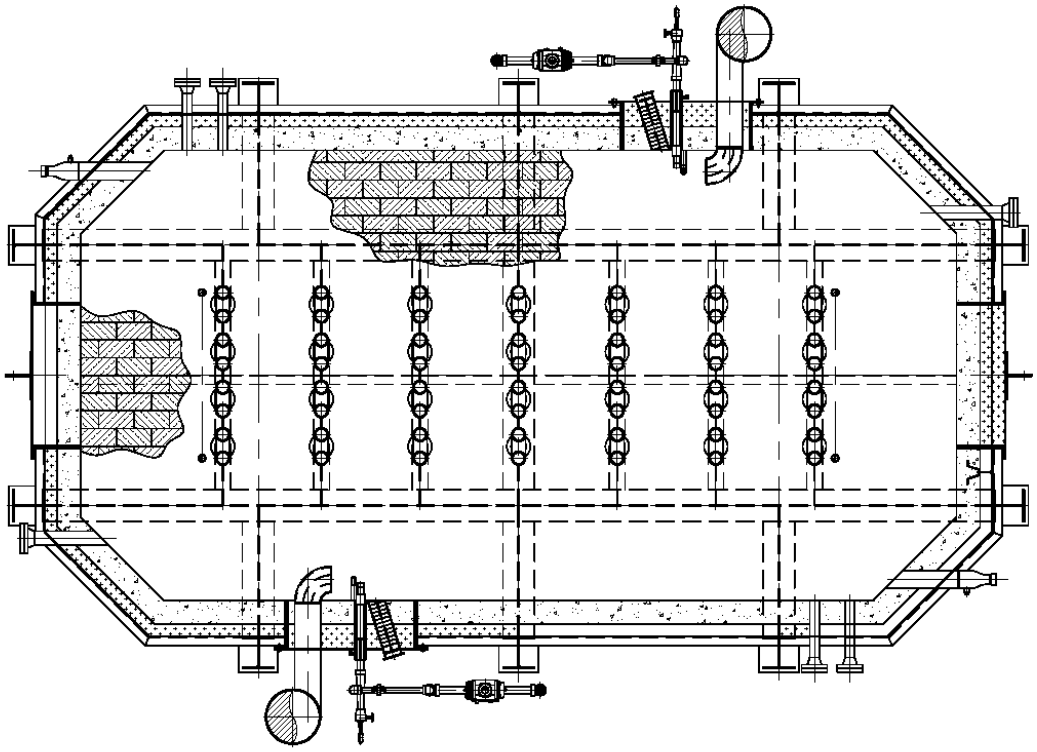
The flameless heater instrumentation at Coffeyville includes not only a Continuous Emissions Monitoring System (CEMS) but also a first out, continuous monitoring data logger. All trips from flameless to conventional firing or full heater shut-downs have been associated with other instrumentation nuisance trips. This has been confirmed by the associated first out continuous data logger.

In summary, GSF has demonstrated over the past 27 months that for all refinery operating conditions and weather conditions the flameless heater has never had a shutdown due to loss of combustion. As long as the flameless heater receives hot combustion air and fuel gas there cannot be a loss of combustion. No longer do flames have to be stabilized on a burner tile. No longer does varying flame speed cause instability.

SCALE UP

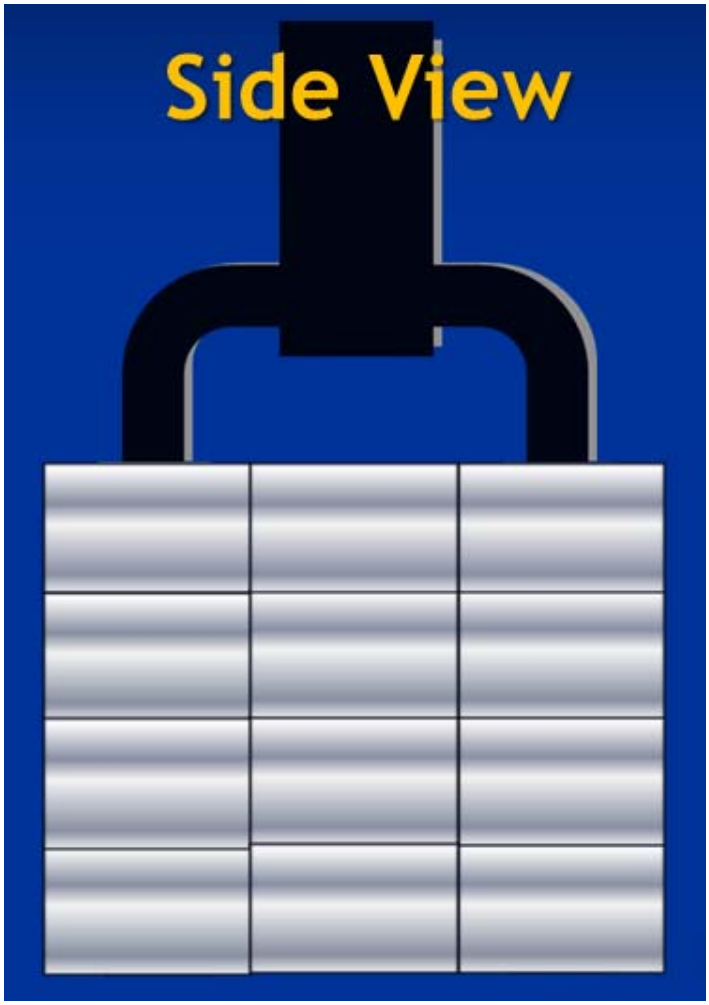
Scale up to any required process heater size is quite simple with the GSF flameless heater design. The existing 10MMBtu/hr flameless heater is designed as a symmetry module so that larger heaters will be an assembly of multiple modules in height and/or length. Figure 3 illustrates the design symmetry of the existing flameless heater.

FIGURE 3 – DESIGN SYMMETRY



The following Figure 4 illustrates how the symmetry modules can be stacked and/or extended in length which allows for simple scale up to accommodate any size of process heater requirements. For heaters larger than 120MMBtu/hr a second heater cell could be added with a common stack. Note: These are conceptual modules for scale up – not shipping modules. Flameless heaters are shipped in the largest convenient shipping size just like conventional heaters.

FIGURE 4 – SCALE UP



Symmetry Modules	Capacity MMBtu/hr
1	10
2	20
3	30
4	40
8	80
12	120

ECONOMICS

Table 3 provides a cost and benefit comparison of a conventional double fired heater with a flameless double fired heater, both with a balanced draft APH system to meet 91% overall efficiency. To fairly compare the two heaters however the reader certainly understands that the conventional system would need to include an SCR for equivalent NOx emissions as the APH required for a 91% efficiency generates significant NOx emissions. Therefore a comparison of a conventional heater with an SCR is also included in the table.

TABLE 3 – BENEFIT COMPARISON

	GSF FLAMELESS DOUBLE FIRED BALANCED DRAFT APH	CONVENTIONAL DOUBLE FIRED BALANCED DRAFT APH	CONVENTIONAL DOUBLE FIRED BALANCED DRAFT APH WITH SCR
Heater Cost, $	Refer To GSF Powerpoint Presentation	Refer To GSF Powerpoint Presentation	Refer To GSF Powerpoint Presentation
SCR Capital Cost, $	NA	NA	1.2MM
NOx, ppmvd	4-8	50-70	4-8
Filter/Coalescer Required	No	Yes	Yes
Flame/Gas Impingement on Tubes	No	Yes	Yes
Increased Run Length	Yes	No	No
Increased Tube Life	Yes	No	No
Even Heat Transfer to Radiant Coil	Yes	No	No
Burner-Burner Flame Interaction	No	Yes	Yes
Multi-Burner Effect NOx Increase	No	Yes	Yes

Obviously these are very general dollar amounts and specific heater application costs will vary based on tube materials, plot space and process requirements. Therefore, the GSF flameless heater costs will also vary. However, the flameless heater will always be the lower cost option with the greatest benefits. GSF will provide detailed cost comparison for any process application upon request.

SUMMARY

The benefits of the GSF Flameless Heater Technology have been clearly proven in Coffeyville Kansas and documented in this paper.

Many are the same benefits associated with any flameless application and documented by numerous technical papers and articles from around the world over the past 20 years.

However, many other benefits documented in this paper are unique and hereto undocumented. GSF now documents the superior thermal performance, processing performance and significant cost reduction of flameless heater technology for refinery process heaters.