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ENV-12-72 **Flameless Technology Demonstration Heater**

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FLAMELESS TECHNOLOGY DEMONSTRATION HEATER

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ABSTRACT

In one of the most recent refinery consent decree (CD) settlements, Coffeyville Resources Refining and Marketing, LLC (CRRM) will be required to conduct a demonstration of “Flameless Heater” Technology. Under the CD, the Flameless Technology Demonstration Heater must have a rated capacity of at least 9.5 MMBtu/hr and be capable of operating in the 100% Flameless Firing mode, combined flameless and Conventional Mode, and 100% Conventional Mode. Additionally, the Flameless Technology Demonstration Heater must be capable of NOx emissions of < 0.01 lbs/MMBtu (HHV) per hour at 3% O2 (dry) when operating in Flameless Firing mode (without SCR) and available to operate 95% of the time while being 90% efficient on a lower heating value basis (“LHV”) when operating in Flameless Firing mode.

The focus of this paper will be to provide the background on flameless technology and outline the CD requirements associated with this flameless technology demonstration. This paper will also provide background and insight on the factors considered in the demonstration heater selection.

FLAMELESS TECHNOLOGY

Great Southern Flameless (GSF) has developed a flameless technology to be used for process heaters in the petroleum refining industry. While High Temperature Air Combustion (HTAC) and Flameless Combustion are not new concepts, they are both new to use in direct fired process heaters in the petroleum refining industry. Concerns regarding safety, operability, and reliability through the wide range of operations required for typical refining heater operations have caused owner/operators concern with implementing this technology. What is needed is a furnace that can be run both conventionally (Ultra-Low NOx) and in the flameless mode (3-8 ppmvd NOx). GSF’s flameless heater design utilizes HTAC for maximum efficiency and CO_2 reduction yet the flameless combustion process produces NOx levels which have previously only been achievable with the use of Selective Catalytic Reduction (SCR) systems. The cost for GSF flameless systems is equivalent to a conventional double fired heater with a conventional balanced draft air preheat system.

Flameless Technology Fundamentals

For conventional combustion burners to be operable there is the rule of the three T’s: Time, Temperature and Turbulence. The fuel and air molecules, along with a relatively low level of inert flue gas molecules in an Ultra-Low NOx burner apparatus, require close spacing, low velocity and turbulence for mixing in order to create a stable primary flame. The stabilized flame creates a localized high temperature flame core which generates significant levels of NOx as well as uneven radiant heat flux to the process coil. Uneven radiant heat flux combined with frequently seen flame impingement causes hot spots, coking, shortened run lengths, reduced throughput and even the possibility of tube rupture.

The flameless combustion reaction also requires time and temperature. However, it is diffusion rather than turbulence which drives the oxidation reaction to completion. Therefore, flameless combustion uses open spacing and high velocity fuel and air which both entrain very high levels of inert flue gas.

An even radiant heat flux to the process coil and the flue gas heat recovery to the combustion air stream provide increased heater efficiency that results in up to an 11% reduction of fired duty and thus an 11% reduction in emissions. This is the equivalent of greater than 90% efficiency on an LHV basis. By reducing stack flue gas temperatures as low as 240^{o}F in the air preheater, additional heat recovery and unit efficiency can be captured. With flameless combustion, the high pre-heated air temperature will not negatively impact NOx emissions. Because flameless combustion does not depend on a stable primary flame with an adiabatic flame temperature of 2400^{o}F or greater, NOx emission levels for a flameless heater are only 3-8 ppm even with HTAC and without an SCR. Refer to Table 1 for comparison details.

Table 1. Heater Technology Comparison

	FLAMELESS MAXIMUM EFFICIENCY	**FLAMELESS BASELINE**	**CONVENTIONAL NATURAL DRAFT**
Air Preheat	Yes	Yes	No
Combustion Air Temp, ^{o}F	890	890	60
Stack Temp, ^{o}F	240	300	650
Bridgewall Temp, ^{o}F	1537	1537	1537
Heat Release (LHV), MMBtu/hr	107.5	109.9	121.2
Heat Efficiency (LHV), %	93	91	82.5
Heat Efficiency (HHV), %	83	81	72.5
Energy Savings (LHV), MMBtu/hr	13.7	11.3	NA
CO, ppmvd	< 50	< 50	< 50
NOx, ppmvd corrected to 3% O2	3 - 8	3 - 8	20
NOx, lb/MMBtu (HHV)	0.006	0.006	0.024
NOx, lb/hr	0.723	0.741	3.31
NOx reduction, lb/hr	2.587	2.569	NA
NOx reduction, %	78.2	77.6	NA
CO2, lb/hr	13,867.5	14,177.1	15,634.8
CO2 reduction, lb/hr	1,767.3	1,457.7	NA
CO2 reduction, %	11.3	9.3	NA

Basis: Radiant Coil Configuration: Double Fired
Absorbed Duty: 100 MMBtu/hr
Fuel Composition: 30% H2, 50% CH4, 20% C3H8
15% Excess Air

GSF's Advanced Flameless Technology

The above fundamentals are well known and proven in the combustion science world and are undisputed, so why are refineries and chemical plant owners not quickly and anxiously converting every heater in the plant to a flameless heater? The answer of course is because of the wide ranging operating parameters that are required for most process heaters. Many heaters require a turndown firing rate of 5:1 or even greater. Many units have wide ranging fuel heating values that swing up and down without notice. Many units run minimum firing rate at Start of Run (SOR) and then are at maximum firing rates at End of Run (EOR). Some units run opposite with higher rates for SOR and ramp down toward EOR. The heater is often the only high temperature heat source for most process units and it must provide dependable heat 24 hours a day, 365 days a year.

There now is a way to have all the efficiency and emissions benefits of flameless combustion along with the flexibility, safety, reliability and operability of a conventional heater. GSF has developed a conventional heater that can also be run in the flameless mode. By using HTAC generated from flue gas heat recovery together with GSF's patented refractory wall texture, localized diffusion zone temperatures are maintained above the auto-ignition temperature of the fuel so the flameless oxidation reaction is sustained even at the lower bulk flue gas temperatures commonly seen in refinery process heaters.

By utilizing an HTAC air pre-heater, heater efficiencies of up to 93% on an LHV basis can be realized. This can equal a reduction in fuel firing and CO_2 emissions of 11% when compared to conventional heaters without an air pre-heat system. The General Arrangement drawing shown in Figure 1 is an example of a typical conventional heater with an air pre-heat system that can also be run in the flameless mode. Figures 2, 3 and 4 provide details of a typical coil arrangement.
An additional technology advancement that mitigates the risk of applying flameless combustion to process heaters is GSF's proprietary fuel delivery system design. The GSF Conventional Heater with Flameless Firing capability is an integrated heat transfer system complete with a control monitoring and management system that safely and reliably transitions back and forth between 100% flameless, 50% conventional with 50% flameless and 100% conventional firing. The control system determines the appropriate firing mode based on local parameters and permissives. When necessary for start-up, shut-down or anytime an upset causes specified local temperatures to drop below the auto-ignition point, the control system will safely and reliably transition from flameless mode to conventional operation. A sketch of the combustion air and fuel nozzle is shown in Figure 5.

During normal operation while firing in flameless mode, NOx emissions are in the single digits (3-8 ppm), without an SCR. Compared to conventional firing, fuel firing rates drop by up to 9% (up to 11% with maximum heat recovery), therefore other pollutant emissions including greenhouse gases (GHG) are reduced proportional to the efficiency increase and the plant saves money on fuel operating costs.

Added benefits of the even radiant heat flux are clean tubes, elimination of hot spots and coking in the process tubes which provide longer run lengths and increased throughput. Additionally, flameless heater fuel nozzles have large single fuel ports thus eliminating the risk of plugging tips, the maintenance cost of frequent cleanings, and the need for a filter/coalescer.

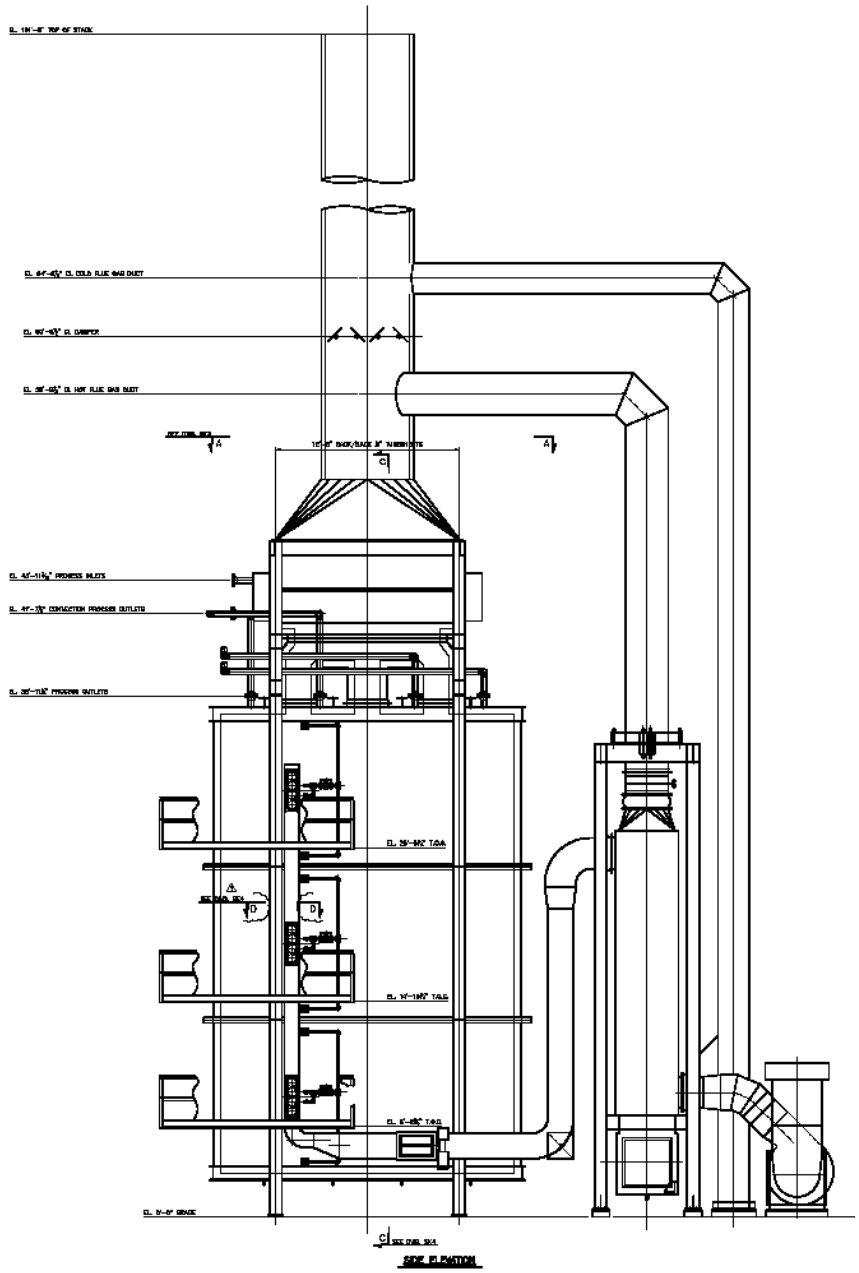

Figure 1. General arrangement of vertical tube, double fired cabin heater

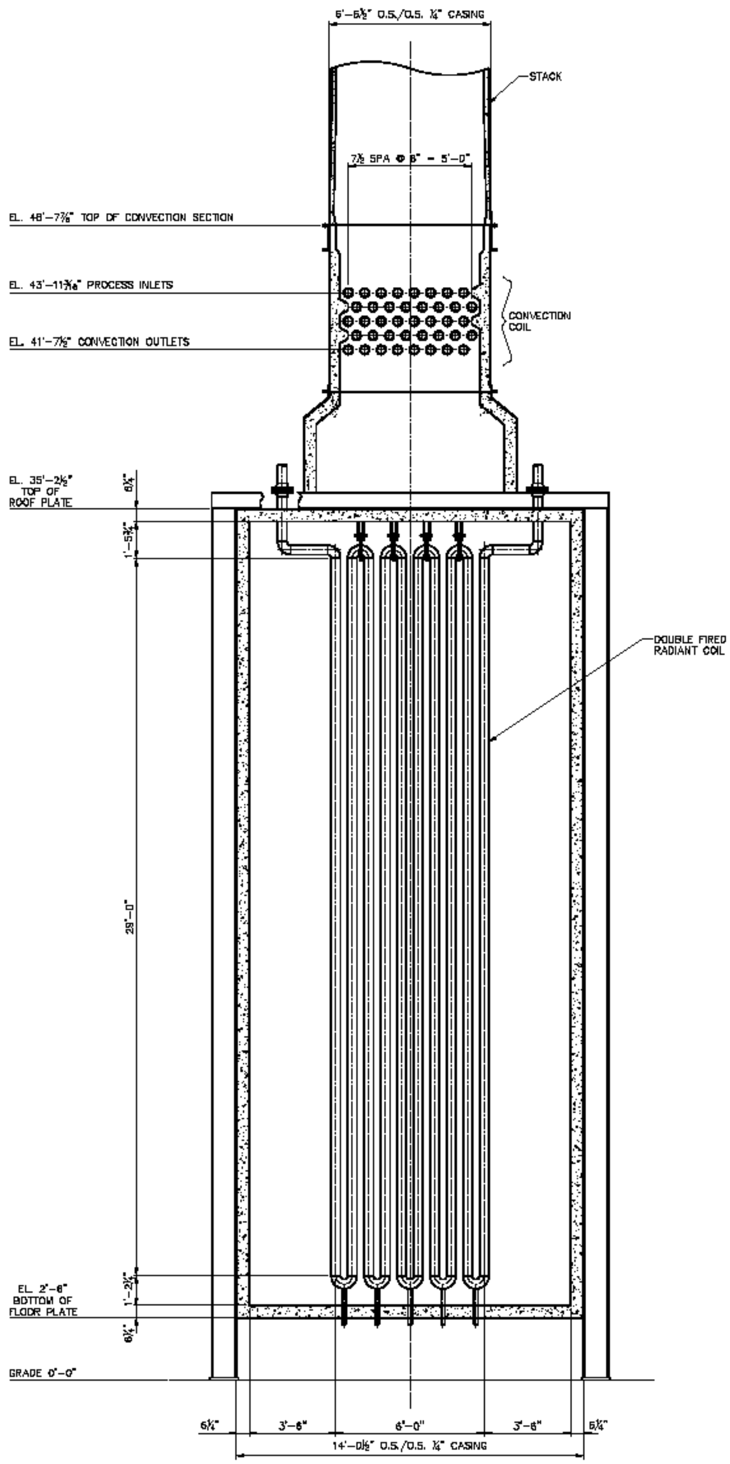

Figure 2. Elevation of coil end view

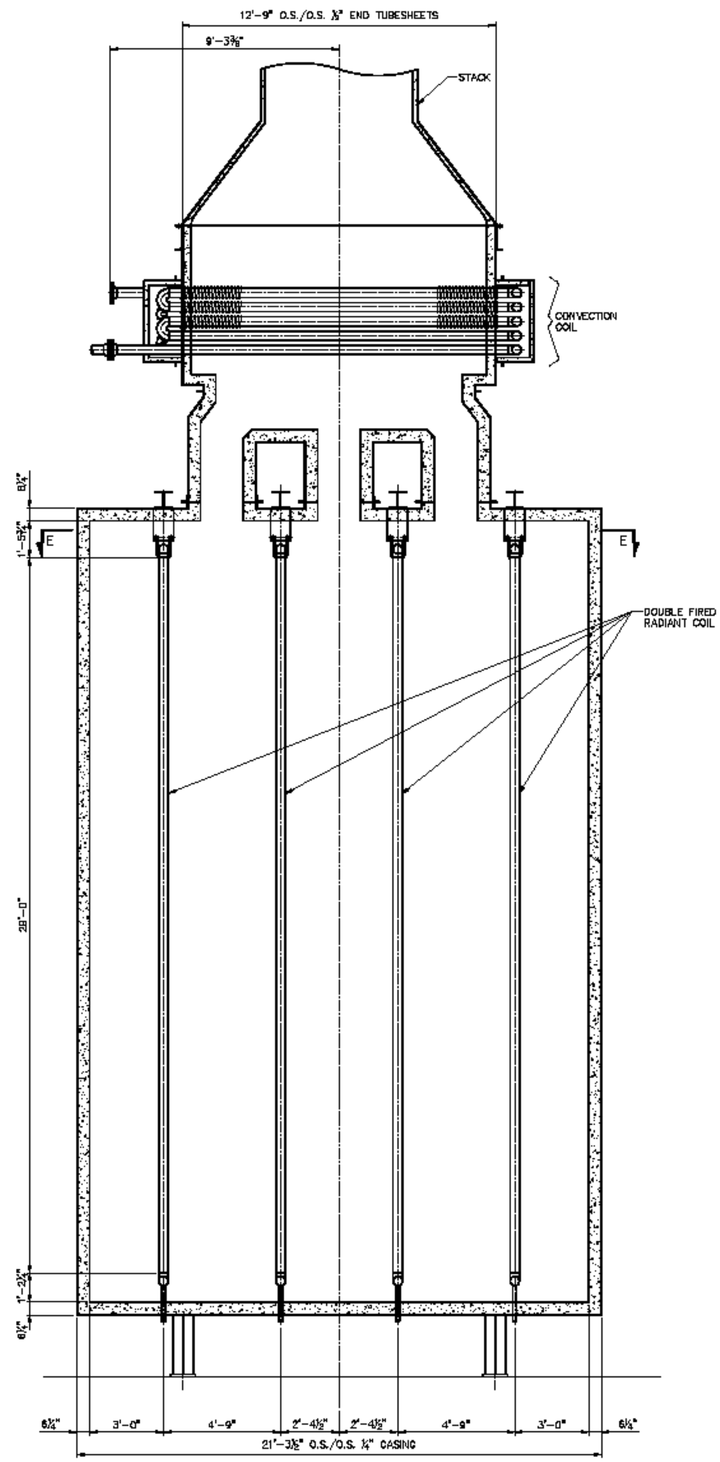

Figure 3. Elevation of coil side view

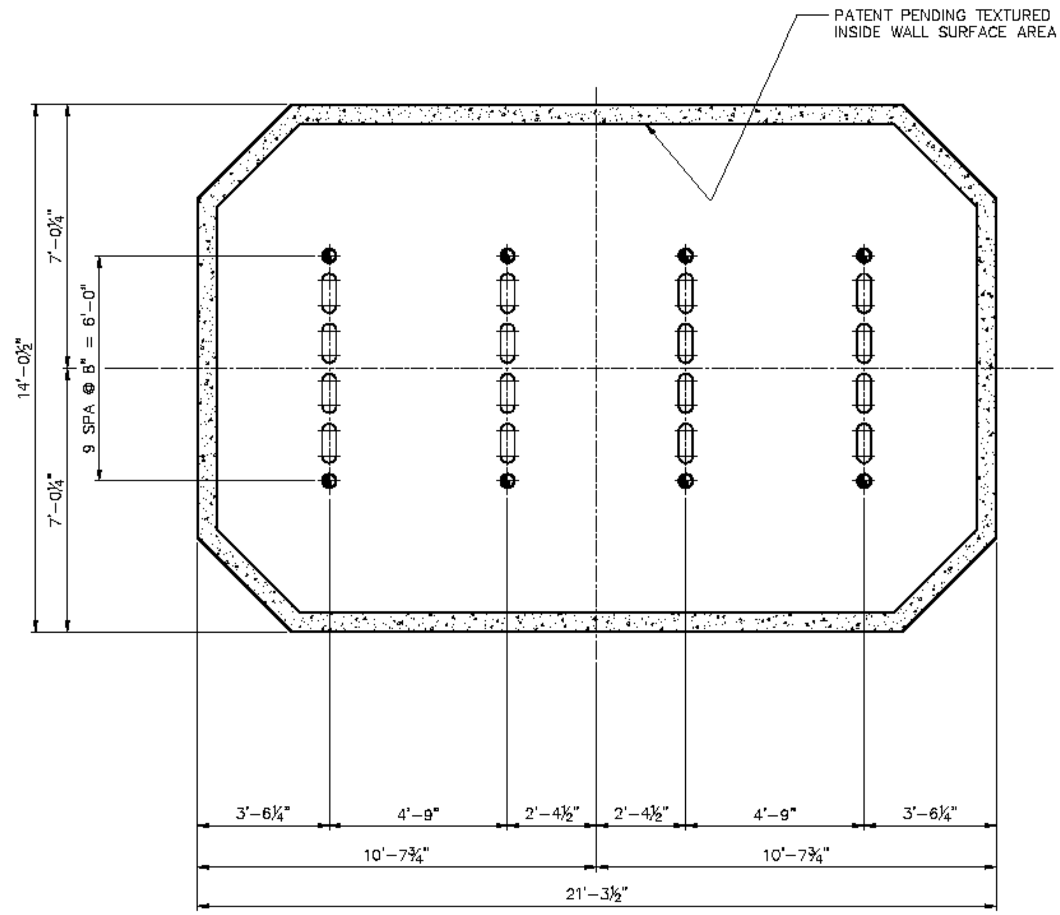

Figure 4. Plan view of coil

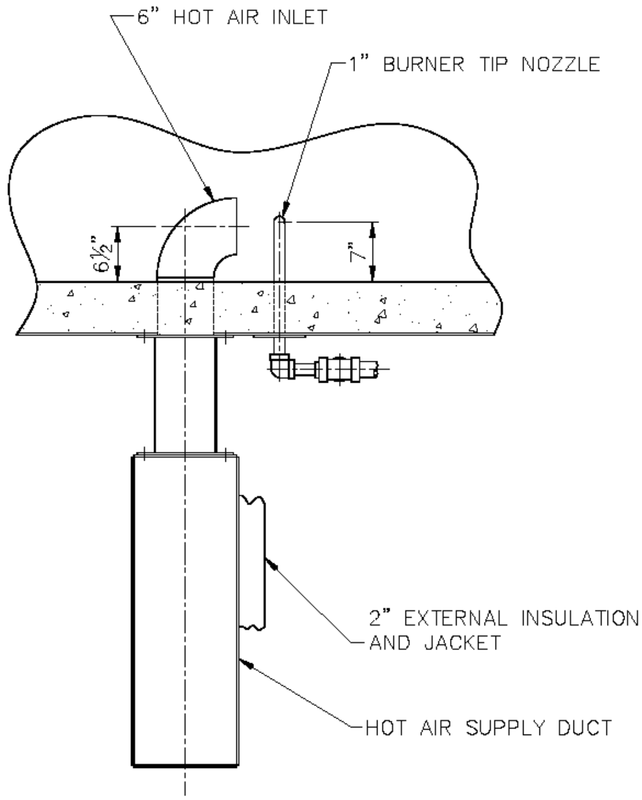

Figure 5. Combustion air and fuel nozzle plan view

<u>Flameless Technology Economics</u>

We can expect that cost for potential GHG cap-and-trade will be set just below the cost for pre and post combustion systems as this will appear attractive to the end user (and will help offset the national deficit!); however, with simple submission to cap-and-trade tax cost, the end user gives up control and receives zero return on investment.

Pre and post combustion processes will be quite costly and will increase operating and maintenance cost, but users will retain control. Note that return on investment will still be zero. The capital cost (equipment plus instrumentation and installation) of a GSF Conventional Heater with Flameless Firing capability is comparable to a typical conventional, double fired heater with a balanced draft, air pre-heat system. Additionally, savings include fuel energy efficiency, reduced maintenance, greater throughput and reduction of the need for emissions credit purchase so there is a measureable return on investment. The end user maintains control over costs (capital and operating) eliminating the unknowns associated with cap-and-trade. See Table 2 for a more detailed equipment cost comparison.

Table 2. Flameless Technology Economic Comparison

	FLAMELESS MAXIMUM EFFICIENCY	FLAMELESS BASELINE	CONVENTIONAL NATURAL DRAFT
Base Heater Cost, $	3,000,000 - 4,000,000	3,000,000 - 4,000,000	3,000,000
Air Preheat Cost, $	837,900	700,000	0.00
Yrs to Pay for Preheat System	0.87	0.88	NA
Flame/Gas Impingement on Tubes	No	No	Yes
Increased Run Length	Yes	Yes	No
Increased Tube Life	Yes	Yes	No
Even Heat Transfer to Radiant Coil	Yes	Yes	No
Burner-Burner Flame Interaction	No	No	Yes
Multi-Burner Effect NOx Increase	No	No	Yes

Basis: Radiant Coil Configuration: Double Fired
Absorbed Duty: 100 MMBtu/hr
Fuel Composition: 30% H2, 50% CH4, 20% C3H8
15% Excess Air
Fuel Cost: $8.00/MMBtu (LHV)

<u>Flameless Technology Summary</u>

With the flexibility of being able to seamlessly transition back and forth between flameless and conventional combustion, there is ZERO risk to meeting production goals and process heat requirements. GSF's Conventional Heater with Flameless Firing capability has the flexibility to operate with wide ranging fuel compositions, including up to 100% H_2 without negatively impacting NOx emissions. Therefore, flameless combustion is a perfect complement to pre-combustion CO_2 reduction technologies. As shown in Table 3, further CO_2 reduction can be achieved by increasing the hydrogen composition of the fuel gas.

GSF's technology can also be designed to utilize 100% oxy-fuel combustion technology to further reduce the size of secondary CO_2 recovery systems that will likely be required in the future.

Table 3. Flameless Technology Economic Comparison

	FLAMELESS MAXIMUM EFFICIENCY	FLAMELESS BASELINE	CONVENTIONAL NATURAL DRAFT
Air Preheat	Yes	Yes	No
Combustion Air Temp, ^oF	890	890	60
Stack Temp, ^oF	240	300	650
Bridgewall Temp, ^oF	1,537	1,537	1,537
Heat Release (LHV), MMBtu/hr	107.5	109.9	121.2
Heater Efficiency (LHV), %	93	91	82.5
Heater Efficiency (HHV), %	83	81	72.5
Energy Savings (LHV), MMBtu/hr	13.7	11.3	NA
CO, ppmvd	<50	<50	<50
NOx, ppmvd corrected to 3% O2	3-8	3-8	20
NOx, lb/MMBtu (HHV)	.006	.006	.024
NOx, lb/hr	0.723	0.741	3.31
NOx reduction, lb/hr	2.587	2.569	NA
NOx reduction, %	78.2	77.6	NA
CO2, lb/hr	12,497.9	12,776.9	15,634.8
CO2 reduction, lb/hr	3,136.9	2,857.9	NA
CO2 reduction, %	20.1	18.3	NA

Basis: Radiant Coil Configuration: Double Fired
Absorbed Duty: 100 MMBtu/hr
Conv. Fuel Composition: 30% H2, 50% CH4, 20% C3H8
Flameless Fuel Composition: 60% H2, 20% CH4, 20% C3H8
15% Excess Air

SUMMARY OF CD REQUIREMENTS FOR FLAMELESS TECHNOLOGY DEMONSTRATION HEATER

As per CD requirements, on or before December 31, 2012, CRRM is required to install a new heater or modify an existing heater, with a rated capacity of at least 9.5 MMBtu/hr, which is capable of operating in Flameless Firing mode (hereinafter “the Demonstration Heater”). The Demonstration Heater will be designed as follows:

a. capable of operating in the following three modes: 100% Flameless Firing mode, combined flameless and Conventional Mode, and 100% Conventional Mode;
b. capable of NOx emissions of <0.01 lbs/MMBtu (HHV) per hour at 3% O2 (dry) when operating in Flameless Firing mode (without SCR);
c. available to operate 95% of the time; and
d. “90% efficient on a lower heating value basis (“LHV”) when operating in Flameless Firing mode.

CRRM is also required to operate the Demonstrator Heater from January 1, 2013 through December 31, 2013 and on or before March 31, 2013, is required to install and operate a continuous emissions monitoring system (CEMs) on the Demonstration Heater for the remainder of the Demonstration Period. Based on operating data collected during the Demonstration Period, CRRM is required to submit a report indicating whether the Demonstration Heater performs in accordance with the design and must propose a lb/MMBtu NOx emission limit on a 365-day rolling average basis.

The results of the Demonstration Period are of significant importance to CRRM, for if the Demonstration Heater performs in accordance with the design, then on or before December 31, 2016, CRRM shall install a new heater or modify an existing heater ("Second Demonstration Heater"), with a firing rate of at least 40 MMBtu/hr, capable of operating in Flameless Firing mode. If required, the Second Demonstration Heater must be designed to the same specifications as the Demonstration Heater. If the Second Demonstration Heater requirement is triggered, CRRM will propose an emission limit for the Second Demonstration Heater by March 31, 2017. If CRRM installs or modifies a Second Demonstration Heater, it may move the CEMs from the Demonstration Heater to the Second Demonstration Heater. If CRRM does not install a Second Demonstration Heater, then after the Demonstration Period it may disconnect the CEMs from the Demonstration Heater.

SELECTION OF FLAMELESS TECHNOLOGY DEMONSTRATION HEATER

After evaluation of potential existing refinery process heaters at the refinery, CRRM has elected to install a new process heater to meet the CD Demonstration Heater requirements. The Demonstration Heater is designed with an absorbed heater duty of 9.5 MMBtu/hr and 14.5 MMBtu/hr (HHV) when used in the combined Flameless and Conventional modes. The Demonstration Heater will be installed in the No. 2 Crude Unit and will fire refinery fuel gas and natural gas as needed. The installation of the Demonstration Heater is planned so that it can operate independently in parallel with the main No. 2 Crude Unit charge heater. This design intuitively makes sense as it minimizes the potential impacts the operation of the Demonstration Heater can have on the No. 2 Crude Unit operation. Similarly, an increase in the No. 2 Crude Unit throughput is not planned to coincide with the Demonstration Heater installation as this also protects the refinery operations from any significant impacts based on the operation of the Demonstration Heater. Thus, if CRRM experiences any difficulties in the startup and/or continued operation of the Demonstration Heater, its impacts on the No. 2 Crude Unit can be minimized as the existing main No. 2 Crude Unit charge heater operates independently and is appropriately sized to handle the planned crude throughput.

Additionally, in selection of the Demonstration Heater, CRRM considered the cost to install CEMs including the associated instrumentation lines. Installing this new heater in the No. 2 Crude Unit presented one of the more cost effective options for the CEMs and instrumentation installation. Moreover, the design of the CEMs package was developed to allow it to be used for the Second Demonstration Heater if the CD requirements for this were triggered.

CRRM reviewed existing refinery process heaters and determined that there was not an existing suitable candidate heater for modification with a firing rate capacity near the 9.5 MMBtu/hr CD threshold. While larger existing process heaters can be modified with the Flameless technology, the cost for engineering and modification of these larger existing units was not desirable in comparison to a new Demonstration Heater. Additionally, CRRM did not have any existing plans for major modifications to any existing heaters that could have been implemented to include Flameless Technology within the CD required deadlines. CRRM also elected to install a new Demonstration Heater rather than modify an existing heater, as designing a new heater with this technology is beneficial in engineering the most reliable heater. While GSF is capable of retrofitting existing conventional heaters with its Flameless technology, the ability to design a new process heater creates greater freedom in the process heater design.

The installation of a new Demonstration Heater as opposed to modification of an existing heater also helps CRRM assure compliance with the CD provisions for "NOx EMISSION REDUCTIONS FROM HEATERS AND BOILERS[1]." Specifically, if CRRM had selected an existing refinery process heater already subject to a permit limit or the CD provisions for NOx emission reductions, the refinery would

[1] Section G - Civ. No. 04-CV-1064-MLB.

need to comply with not only the CD Demonstration Heater requirements but also the other applicable permit limits and/or CD requirements. Thus, in selecting to install a new Demonstration Heater rather than modify an existing process heater, CRRM effectively limited the potential to exceed any existing permit limits and/or comply with separate CD provisions regarding NOx emission reductions from heaters and boilers.

To date an approval for the construction of the Demonstration Heater has been issued by the Kansas Department of Health and Environmental (KDHE) and CRRM has begun the project for its installation. The permitted emissions for the Demonstration Heater include NOx emissions based on vendor supplied factors of 0.096 lb NOx/MMBtu (Conventional Firing Mode), 0.048 lb NOx/MMBtu (Staged Fuel Mode), and 0.01 lb NOx/MMBtu (Flameless Mode). NOx emissions were calculated based on the maximum design firing rate for the heater and based on 15% operation in the Conventional Firing Mode, 15% in the Staged Fuel Mode, and 70% in the Flameless Mode.

SUMMARY

Flameless technology could be a key factor in providing an economically feasible mechanism to meeting anticipated future lower emission limits from process heaters. Flameless technology combined with pre and post combustion technologies can further reduce emissions in order to meet long term compliance requirements. The results to come from CRRM's CD required Demonstration Heater will be of great interest to both the petroleum refining and petrochemical industries as its application may determine a new preferred, cost effective technology to be utilized for process heaters.