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FLAMELESS COMBUSTION APPLIED TO DIRECT FIRED PROCESS HEATERS FOR REDUCTION OF NO_x AND CO_2

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ABSTRACT

US President Barack Obama has already pledged to back energy legislation under his administration that will reduce greenhouse gas emissions 16% by the year 2020 and 80% by the year 2050. His plan calls for a cap-and-trade regulation to achieve these goals. With such aggressive regulations and associated capital expenditures, we can no longer wait for “someone else to be first” to implement all of the energy saving and emission reducing technologies that are already available today.

The extreme legislation to be proposed will likely require a solution utilizing a combination of multiple technologies including:

1) Pre-combustion fuel conditioning
2) High efficiency combustion technologies such as HTAC, Flameless Combustion and Oxy-fuel systems
3) Post-combustion CO_2 capture and storage

Globally, major companies and government entities have already come together and are well underway in developing technologies in the areas of Carbon Capture and Storage. Pre-combustion fuel conditioning systems such as steam-hydrogen reforming are also in development and pilot scale testing as are oxy-burner technologies for direct fired heaters.

While HTAC and Flameless Combustion are not at all new concepts, they are both new to the direct fired process heater industry. Concerns regarding safety, operability and reliability through the wide range of operations required for typical refining heater operations have caused owner/operators to resist being the first to implement such 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). Flameless combustion heater designs will meet the process radiant flux requirements, increase efficiency and reduce emissions during normal operations. Such a heater must include a burner management system which monitors and controls the burner and heater as an integrated heat transfer system.

Great Southern Flameless (GSF) has developed this revolutionary flameless technology for process heaters. GSF’s design utilizes HTAC for maximum efficiency and CO_2 reduction yet the flameless combustion process produces NO_x levels which have previously only been achievable with an SCR. The cost of this system is equivalent to a conventional double fired heater with a conventional balanced draft air preheat system.

TECHNICAL PAPER

1. INTRODUCTION

With the looming energy legislation that is expected to call for an 80% reduction of CO_2 greenhouse gas emissions by 2050, along with a short term goal of 16% reduction by 2020, we must move forward now with a combination of new strategies and technologies. During the mid-1990's, Ultra-Low NO_x burners were just rolling out as the new, best available combustion technology and there was certainly a level of resistance and discomfort among end users to make the change from their good old reliable conventional burners. Strict air quality regulations enforced by government monitoring and costly fines were the incentives that eventually drove the change. Today, Ultra-Low NO_x burners are the norm and are widely accepted as the standard burner technology in plants around the world. Cap-and-trade regulation on CO_2 emissions will again be the economic incentive for driving end users out of their comfort zones to embrace new and innovative technologies.

Calling for an 80% reduction in emissions is equivalent to rolling back the calendar over 100 years to achieve the emission levels of circa 1905. It's seemingly impossible to think that we can meet such an aggressive goal. Industry, academia and government entities must come together, work together and succeed in reaching realistic goals and in finding the most economic course of doing so.

Research and development is currently ongoing along many parallel paths to identify viable strategies and technologies that will move industry towards the goal. Pre-combustion fuel conditioning and post-combustion CO_2 capture and storage for instance are both technologies that are being engineered and tested under global commitments such as the CO_2 Capture Project[1] and are comprised of key industry leaders, academic institutions and government entities. In addition to these pre and post combustion technologies we must consider the actual combustion process as well. Maximizing heater system efficiency obviously reduces the total firing requirements and of course the total flue gas emissions. This will be the area of focus for this paper and presentation by Great Southern Flameless, LLC.

Flameless combustion is not at all a new technology. It has been a well proven and standard combustion method used in many high temperature heat transfer applications for decades. In typical refinery processes however it has been avoided due to relatively lower radiant zone temperatures and flux rates (when compared to the steel or glass industry), broad range of operating requirements and wide ranging fuel compositions. Great Southern has two patents pending on newly developed flameless heater technologies that now overcome these barriers for typical refinery process heaters.

2. 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 NO_x 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 NO_x 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 a 11% reduction of fired duty and thus an 11% reduction in greenhouse gas emissions. This is the equivalent of greater than 90% efficiency on an LHV basis. By reducing stack flue gas temperatures as low as 240 °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 NO_x emissions. Because flameless combustion does not depend on a stable primary flame with an adiabatic flame temperature of 2400°F or greater, NO_x emission levels for a flameless heater are only 3-8 ppm even with high temperature air combustion (HTAC) and without an SCR. Refer to Table 1 for comparison details.

	FLAMELESS MAXIMUM EFFICIENCY	FLAMELESS BASELINE	CONVENTIONAL NATURAL DRAFT
Air Preheat	**Yes**	**Yes**	**No**
Combustion Air Temp, °F	**890**	**890**	**60**
Stack Temp, °F	**240**	**300**	**650**
Bridgewall Temp, °F	**1537**	**1537**	**1537**
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	**13867.5**	**14177.1**	**15634.8**
CO2 reduction, lb/hr	**1767.3**	**1457.7**	**NA**
CO2 reduction, %	**11.3**	**9.3**	**NA**

Table 1. Heater technology comparison
Basis: Radiant Coil Configuration: Double Fired
Absorbed Duty: 100 MMBtu/hr
Fuel Composition: 30% H2, 50% CH4, 20% C3H8
15% Excess Air

3. GREAT SOUTHERN'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 SOR and then are at maximum firing rates at EOR. Some units run opposite with higher rates for SOR and ramp down toward EOR. The heater is 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. Great Southern 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 Great Southern's proprietary 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 our proprietary fuel delivery system design. The Great Southern 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 or to a mid-point operation, neither of which produces any more NO_x than staged fuel Low-NO_x burners or Ultra-low NO_x burners respectively. A sketch of the combustion air and fuel nozzle is shown in Figure 5.

During normal operation while firing in flameless mode, NO_x 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 greenhouse gases 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 fuel ports thus eliminating the risk of plugging tips, the maintenance cost of frequent cleanings, and the need for a filter/coalescer.

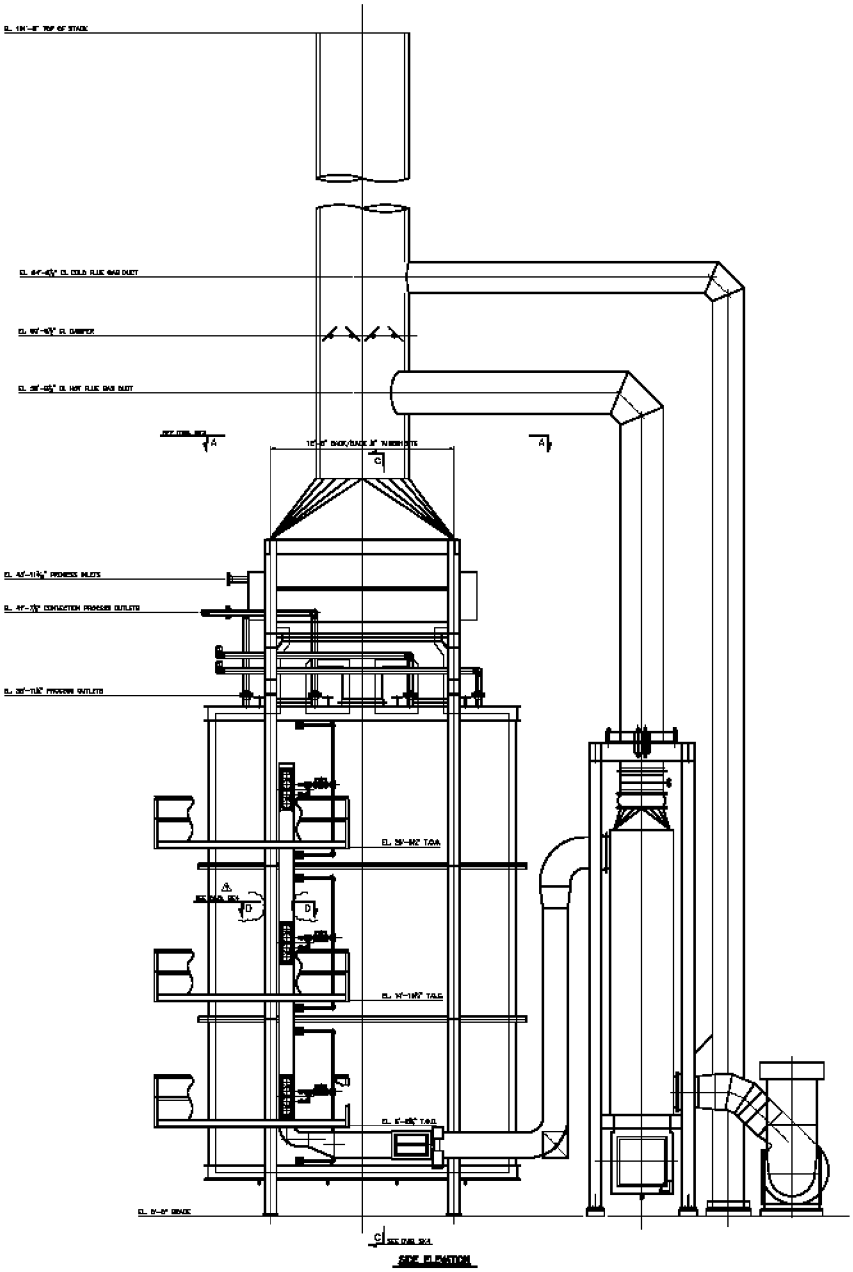

Figure 1. General arrangement of vertical tube, double fired cabin heater

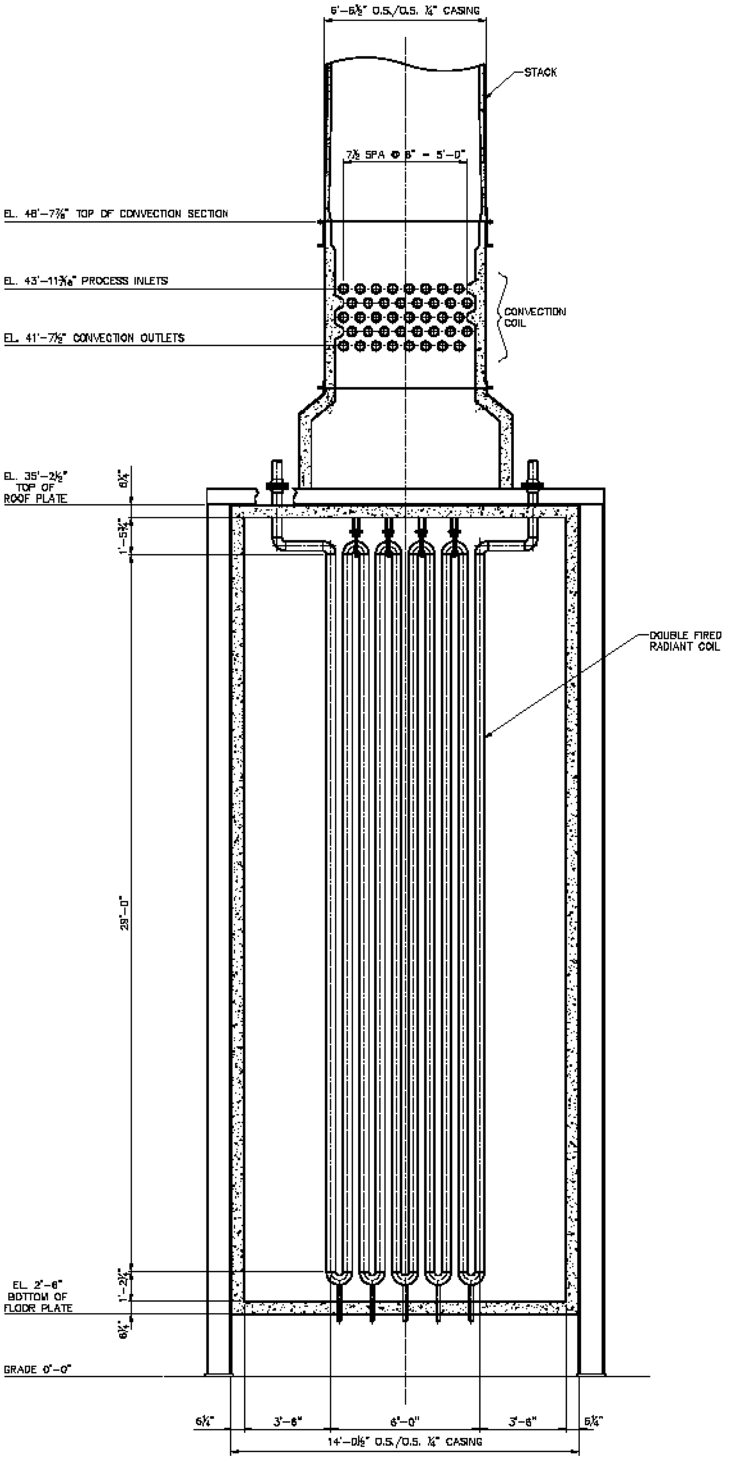

Figure 2. Elevation of coil end view

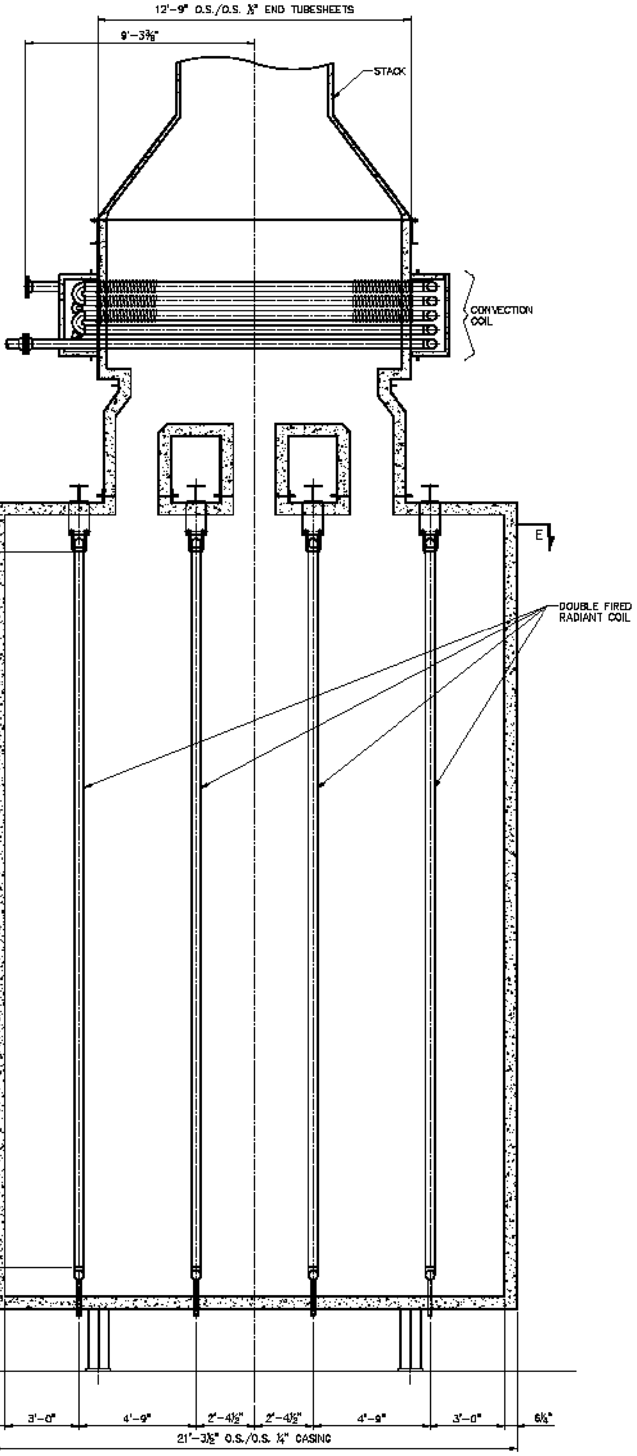

Figure 3. Elevation of coil side view

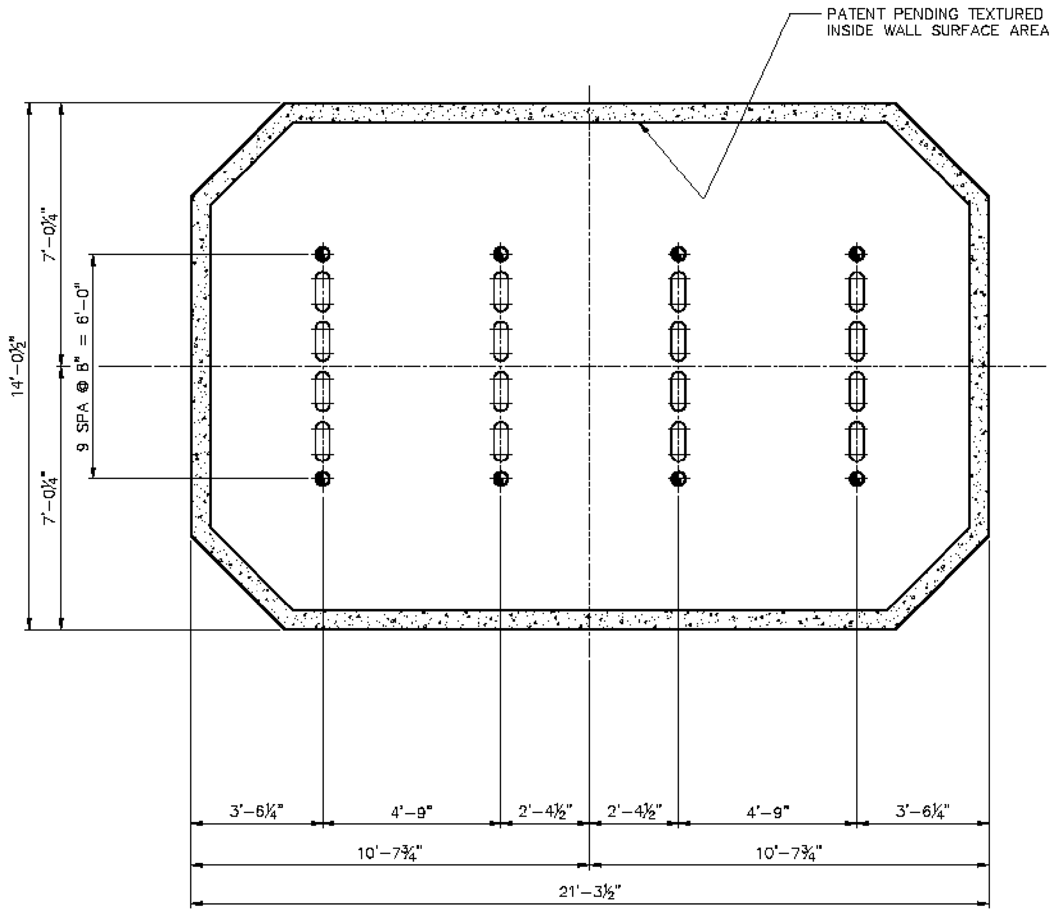

Figure 4. Plan view of coil

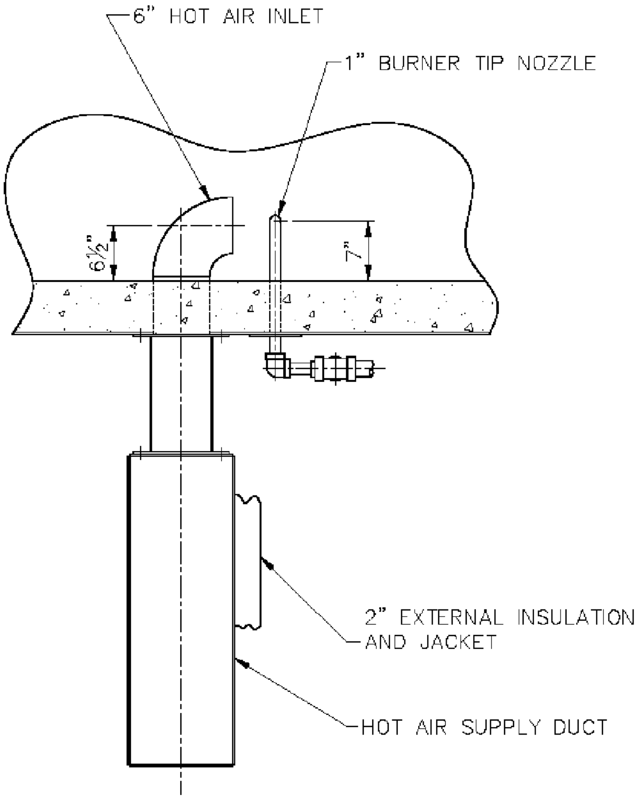

Figure 5. Combustion air and fuel nozzle plan view

4. ECONOMICS

We can expect that cost for 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 Great Southern 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.

	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**

Table 2. Flameless technology economic comparison

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)

5. SUMMARY

The Great Southern Flameless combustion technology is approved by the EPA for consent decree NO_x compliance. Flameless combustion is sure to become the next BACT required by air quality boards to help meet NO_x and greenhouse gas emissions regulations and compliance. 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 requirement.

Great Southern'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 NO_x 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.

Great Southern'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.

	FLAMELESS MAXIMUM EFFICIENCY	FLAMELESS BASELINE	CONVENTIONAL NATURAL DRAFT
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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	**12497.9**	**12776.9**	**15634.8**
CO2 reduction, lb/hr	**3136.9**	**2857.9**	**NA**
CO2 reduction, %	**20.1**	**18.3**	**NA**

Table 3. Flameless technology economic comparison

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

Flameless technology will be a key factor in economically bringing the industry to the 2020 (16% reduction) goal line. Flameless technology combined with pre and post combustion technologies can further reduce emissions in order to meet long term compliance requirements. We are eager to participate and work together with industry leaders, academia and air quality government groups to successfully bring all these clean air technologies together in the most economic way possible and support the implementation of each throughout the industry.

REFERENCES

[1] CO$_2$ Capture Project; http://www.co2captureproject.org/aboutus.html