REDUCTION OF NOX EMISSIONS FROM FIRED HEATERS WITH COMBUSTION AIR PREHEATERS

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ABSTRACT

A fired heater unit is disclosed having a radiant section having a high emissivity coating therein. The fired heater unit also includes a burner for mixing fuel and preheated air to produce flue gas to be used in heating operations within the unit, and a preheater for heating ambient air with the flue gas to produce the preheated air for use in the burner. Other process streams are heated with the flue gas in the radiant section and a convection section operatively connected to the radiant section prior to venting the flue gas to atmosphere. The fired heater unit, and associated processes, result in a reduction of NOx emissions over conventional systems and methods.
REDUCTION OF NOX EMISSIONS FROM FIRED HEATERS WITH COMBUSTION AIR PREHEATERS

TECHNICAL FIELD

[0001] The present application generally relates to the reduction of mono-nitrogen oxides (NOx) emissions from fired heaters using fuel gas. More particularly, the present application relates to the reducing NOx emissions from fired heaters having a combustion air preheater while improving efficiency using high emissivity coatings.

BACKGROUND

[0002] In chemical processing and petrochemical production and refining operations, fired heaters are typically employed because these heaters can provide a higher level of heat, which typically cannot be obtained from other utility sources. Fired heaters are heat exchangers that use hot gases of combustion to raise the temperature of a feed flowing through coils of tubes aligned throughout the heater. Conventional fired heaters with extensive heat recovery presently in commercial practice contain a radiant section, a convection section above the radiant section, a combustion air preheater, and a burner. Generally, fuel flows into the burner and is mixed with preheated combustion air. The resulting flames from the combustion heat up tubes within the radiant section, which in turn heat the fluid inside the radiant section to a desired temperature. Flue gas from the combustion exits the radiant section and enters the convection section, where more heat is recovered via convection before venting to the atmosphere.

[0003] Conventional fired heaters are a major source of NOx emissions. Currently, low NOx burners or selective catalytic reduction can be used to reduce NOx emissions. However, these methods are generally expensive and difficult to operate. Adiabatic flame temperature reduction is another method of reducing NOx emissions. Conventional efforts to reduce flame temperature may include introducing flame diluents to the flame. However, these methods can lead to unstable flames, flame extinction, or flame blow-out that can create potentially dangerous operating conditions. For example, air contains a significant amount of oxygen, which is an oxidizing agent. If fuel is introduced to the air stream at an inappropriate location, this can create conditions for flame instability and/or a “flame out” to occur. In unstable and/or “flame out” conditions, the flame is either partly or fully extinguished such that flammable gas enters the furnace, potentially resulting in an explosion. In addition, the ingress of air can also reduce heater efficiency resulting in increases in total NOx emissions.

[0004] In addition, some fired heaters that do not employ preheated combustion air will utilize high emissivity coatings in the radiant section to increase the radiant efficiency of the fired heater. While the total amount of NOx emitted is lowered due to decreased firing, the NOx concentration in the exiting flue gas is essentially unchanged because the adiabatic flame temperature still remains the same. Accordingly, for fired heaters with extensive convection section heat recovery, increasing the radiant efficiency will not result in a corresponding increase in overall (fired) efficiency since the flue gas cannot be cooled below its dew point.

[0005] With an ever increasing demand on fuel, its rising cost, and at the same time tighter regulatory control on emissions reduction, there is a need for a fired heater that maximizes heater efficiency while reducing NOx emissions.

SUMMARY

[0006] The present invention is directed to fired heater units and processes for reduction of NOx emissions from fired heaters using fuel gas. In one aspect of the invention, the fired heater unit includes a burner, a radiant section, a convection section, a plenum, and a flow path extending from the burner to the plenum. Fuel and preheated combustion air are mixed in the burner to produce a hot flue gas. The flue gas flows to the radiant section, where it is utilized to heat by radiant heat transfer a process stream, such as from a boiler, reformer, or process heater application. The radiant section includes a high emissivity refractory coating therein, which acts to improve radiant section efficiency unlike conventional uncoated refractories that suffer significant lowering of emissivity at radiant section operating temperatures. The increased efficiency of the radiant section allows the same duty to be transferred at lower temperatures, thereby allowing a reduction of the preheated air temperature and resulting in a lower flame temperature that reduces NOx emissions. The flue gas then flows to the convection section, where it is again utilized to heat by convection another process stream. The flue gas continues on into the plenum, where a preheater unit is operatively coupled to therein, and is utilized to heat ambient air to produce the preheated combustion air that flows into the burner. The flue gas is then vented to atmosphere. The fired heater unit, and associated processes, result in a reduction of NOx emissions over conventional systems and methods.

[0007] The features of the present invention will be readily apparent to those skilled in the art upon a reading of the description of the preferred embodiments that follows.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] For a more complete understanding of the exemplary embodiments of the present invention and the advantages thereof, reference is now made to the following description in conjunction with the accompanying drawings, which are briefly described as follows.

[0009] FIG. 1A is a schematic diagram of a NOx emission reducing system, according to an exemplary embodiment.

[0010] FIG. 1B is a process diagram of the NOx emission reducing process system of FIG. 1A, according to an exemplary embodiment.

[0011] FIG. 2 is a process diagram of a NOx emission reducing system for use in boiler applications, according to an exemplary embodiment.

[0012] FIG. 3 is a process diagram of a NOx emission reducing system for use in reformer applications, according to an exemplary embodiment.

[0013] FIG. 4 is a process diagram of a NOx emission reducing system for use in reformer applications, according to another exemplary embodiment.

[0014] FIG. 5 is a process diagram of a NOx emission reducing system for use in process heater applications, according to an exemplary embodiment.

DETAILED DESCRIPTION

[0015] Illustrative embodiments of the invention are described below. In the interest of clarity, not all features of an actual implementation are described in this specification. One
of ordinary skill in the art will appreciate that in the development of any such actual embodiment, numerous implementation-specific decisions must be made to achieve the developers' specific goals, such as compliance with system-related and business-related constraints, which will vary from one implementation to another. Moreover, it will be appreciated that such a development effort might be complex and time-consuming, but would nevertheless be a routine undertaking for those of ordinary skill in the art having the benefit of this disclosure.

[0016] The present invention may be better understood by reading the following description of non-limitative embodiments with reference to the attached drawings wherein like parts of each of the figures are identified by the same reference characters. The words and phrases used herein should be understood and interpreted to have a meaning consistent with the understanding of those words and phrases by those skilled in the relevant art. No special definition of a term or phrase, for example, a definition that is different from the ordinary and customary meaning as understood by those skilled in the art, is intended to be implied by consistent usage of the term or phrase herein. To the extent that a term or phrase is intended to have a special meaning, for example, a meaning other than that understood by skilled artisans, such a special definition will be expressly set forth in the specification in a definitional manner that directly and unequivocally provides the special definition for the term or phrase. Moreover, various streams or conditions may be referred to with terms such as "hot," "cold," "cooled," "warm," etc., or other like terminology. Those skilled in the art will recognize that such terms reflect conditions relative to another process stream, not an absolute measurement of any particular temperature.

[0017] The present application is directed to processes for improving efficiency and reducing NOx emissions from fired heaters, wherein such benefits are realized by utilizing preheated combustion air and high emissivity coatings to overcome the aforementioned issues with current systems. The present application is also directed to systems for implementing such processes.

[0018] Referring now to FIGS. 1A-1B, a NOx emission reducing system 100 having a fired heater unit 102 for providing heat energy to a fuel stream 104 is illustrated. The fired heater unit 102 has a first end 102a and a second end 102b, and a flue gas flow path (not shown) extending from the first end 102a to the second end 102b. The fuel stream 104 can be a liquid, vapor, or solid fuel stream. The fuel stream 104 enters a burner 106 where it is mixed with a preheated combustion air stream 108. In certain exemplary embodiments, the combustion air stream 108 has a temperature in the range of from about 310 to about 900 degrees Fahrenheit (°F). In certain embodiments, the combustion air stream 108 has a temperature that has a temperature significantly greater than an ambient combustion air stream used in a conventional fired heater, as illustrated in the Example below. The fuel stream 104 is combusted to produce a first flue gas stream 110 (FIG. 1B) that flows along the flue gas flow path. The first flue gas stream 110 generally includes carbon dioxide (CO2) and water (H2O). In certain embodiments, the first flue gas stream 110 also includes nitrogen (N2) and oxygen (O2) from any excess combustion air present. The first flue gas stream 110 also contains small amounts of pollutants such as NOx, carbon monoxide (CO), and unburned hydrocarbons. In particular, the amount of NOx produced is a function of the adiabatic flame temperature and excess air. Lowering the adiabatic flame temperature generally lowers NOx emissions for the same amount of excess air. The temperature of the first flue gas stream 110 is the adiabatic flame temperature and generally depends on the temperature and amount of fuel stream 104 and combustion air stream 108. In certain exemplary embodiments, the adiabatic flame temperature is in the range of from about 2000 to about 3000°F.

[0019] The fired heater unit 102 includes a radiant section 114 for providing high level heat (primarily by radiant heat transfer) to a process stream 116. The radiant section 114 includes a high emissivity coating that allows for the total furnace duty and efficiency to remain the same, but with a lower temperature combustion air stream 108 when compared to conventional fired heater systems with extensive convection section heat recovery. Generally, the high emissivity coatings for use in the present invention include ceramic materials that include small particles of one or more inorganic materials. Suitable inorganic materials for use in the coatings include, but are not limited to silicon, aluminum, iron, titanium, sodium, potassium, calcium, magnesium, zirconium, and boron. In certain embodiments, the high emissivity coating is present on one or more interior walls of the radiant section 114, which may also include tubes (not shown) in the radiant section. In certain exemplary embodiments, the high emissivity coating is present on all of the interior walls of the radiant section 114. Heat from the first flue gas stream 110 is used to heat up the tubes within the radiant section 114, which in turn heat the process stream 116 to a desired temperature to produce a heated process stream 118. In certain embodiments, the heated process stream 118 has a temperature in the range of from about 500 to about 1800°F. The first flue gas stream 110 is cooled to produce a second flue gas stream 120. In certain exemplary embodiments, the second flue gas stream 120 has a temperature in the range of from about 900 to about 1000°F.

[0020] The fired heater unit 102 also includes a convection section 124 positioned adjacent to the radiant section 114. The second flue gas stream 120 exits the radiant section 114 along the flue gas flow path and enters the convection section 124, where more heat is recovered via convection. The convection section 124 recovers usable sensible heat in the second flue gas stream 120 to heat a process and/or utility stream 126 to produce a heated process stream 128 and a third flue gas stream 130. In certain exemplary embodiments, the heated process stream 128 has a temperature in the range of from about 100 to about 1200°F. In certain exemplary embodiments, the third flue gas stream 130 has a temperature in the range of from 200 to about 900°F.

[0021] The fired heater unit 102 further includes a plenum 132 operatively coupled to the convection section. The third flue gas stream 130 exits the convection section 124 along the flue gas flow path and enters the plenum 132. In certain exemplary embodiments, a heat exchanger or a preheater unit, such as a combustion air preheater 134, is present in the plenum 132, and heat from the third flue gas stream 130 is used to heat an ambient combustion air stream 136 (at ambient pressure and temperature) to produce the combustion air stream 108 (that enters the burner 106) and a fourth flue gas stream 140. In certain exemplary embodiments, the fourth flue gas stream 140 is at its dew point, and may have a temperature of greater than about 200°F. In certain embodiments, the fired heater unit 102 includes an induced draft fan 142 (FIG. 1B) to pull the fourth flue gas stream 140 through to vent at the second end 102b as flue gas stream 144 to the
atmosphere. In certain exemplary embodiments, the system 100 includes a forced draft blower or fan 148 to compress the ambient combustion air stream 136 to produce a compressed combustion air stream 150 to be fed to the combustion air preheater 134. In certain exemplary embodiments, the compressed combustion air stream 136 has a pressure in the range of from about 14.7 to about 30 pounds per square inch absolute (psia). Generally, the compressed combustion air stream 136 has a suitable pressure for overcoming the pressure drops imposed by the combustion air preheater 134 and the burner 106.

FIG. 2 illustrates a NOx emission reducing system 200, according to another exemplary embodiment. The NOx emission reducing system 200 is the same as that described above with regard to NOx emission reducing system 100, except as specifically stated below. For the sake of brevity, the similarities will not be repeated hereinbelow. The fired heater unit 102 can be utilized in boiler applications. Referring now to FIG. 2, the radiant section 114 provides high level heat by radiant heat transfer to a boiler feedwater stream 216 to produce a saturated steam stream 218. In certain embodiments, the saturated steam stream 218 is at its boiling point. In addition, the convection section 124 can be utilized to heat a process stream 226 to produce a heated process stream 228. In certain embodiments, the process stream 226 is a boiler feedwater stream and the heated process stream 228 is a preheated boiler feedwater stream. In other embodiments, the process stream 226 is a boiler feedwater stream and the heated process stream 228 is a saturated steam stream. In yet other embodiments, the process stream 226 is a saturated steam stream and the heated process stream 228 is a superheated steam stream. In certain exemplary embodiments, the process stream 226 has a temperature in the range of from about 212 to about 800°F. In certain exemplary embodiments, the heated process stream 228 has a temperature in the range of from about 300 to about 1000°F.

FIG. 3 illustrates a NOx emission reducing system 300, according to another exemplary embodiment. The NOx emission reducing system 300 is the same as that described above with regard to NOx emission reducing system 100, except as specifically stated below. For the sake of brevity, the similarities will not be repeated hereinbelow. The fired heater unit 102 can be utilized in steam methane reformer applications. Referring now to FIG. 3, the radiant section 114 provides a heat of reaction to a process stream 316 to produce a synthesis gas stream 318. In certain embodiments, the process stream 316 includes natural gas, naphtha or other light liquid hydrocarbons, and steam. In certain exemplary embodiments, the process stream 316 has a temperature in the range of from about 100 to about 700°F. In certain embodiments, the synthesis gas stream 318 contains hydrogen (H₂), carbon dioxide (CO₂), carbon monoxide (CO), water (H₂O), methane (CH₄), and small amounts of residual hydrocarbons and inert gases (for instance, nitrogen (N₂) and argon (Ar)). In certain exemplary embodiments, the synthetic gas stream 318 has a temperature in the range of from about 200 to about 1200°F. Generally, the reaction is endothermic, and extensive heat recovery, such as superheating, saturated steam generation, and feed preheats, is provided in the convection section 124.

FIG. 4 illustrates a NOx emission reducing system 400, according to another exemplary embodiment. The NOx emission reducing system 400 is the same as that described above with regard to NOx emission reducing system 100, except as specifically stated below. For the sake of brevity, the similarities will not be repeated hereinbelow. The fired heater unit 102 can be utilized in catalytic reformer applications. Referring now to FIG. 4, the radiant section 114 provides a heat of reaction to a process stream 416 to produce a partially converted stream 418. In certain exemplary embodiments, the partially converted stream has a temperature in the range of from about 100 to about 1000°F. In certain embodiments, the process stream 416 includes naphtha and gasoline to be converted to higher octane gasoline components by isomerization and dehydrogenation reactions. In certain embodiments, the partially converted stream 418 produced can include unconverted feedstock, hydrogen (H₂), cyclo-paraffins, and aromatics. Generally, the reaction is moderately endothermic, and several reactors can be set up in series with fired heater units between each stage.

FIG. 5 illustrates a NOx emission reducing system 500, according to another exemplary embodiment. The NOx emission reducing system 500 is the same as that described above with regard to NOx emission reducing system 100, except as specifically stated below. For the sake of brevity, the similarities will not be repeated hereinbelow. The fired heater unit 102 can be utilized in process heater applications, and can be used to heat a wide variety of feed streams found in refineries and petrochemical plants, including feed and reboilers to distillation columns, processing units, and guard beds. Referring now to FIG. 5, the radiant section 114 provides a heat to a process stream 516 to produce a heated process stream 518. In certain embodiments, the heated process stream 518 has a temperature in the range of from about 300 to about 1000°F. In addition, the convection section 124 can include additional preheated feed stream(s) (not shown).

The present application is generally directed to fired heater systems and processes for providing high levels of heat in chemical processing and petrochemical production and refining operations. The exemplary systems may include a fired heater unit having a combustion air preheater, a burner, a radiant section coated with a high emissivity coating, and a convection section. The overall NOx emissions from the systems of the present invention is reduced when compared to conventional systems because the high emissivity coatings increase the efficiency of the radiant section and allows for the same heat transfer duty at lower temperatures. This increased efficiency allows for a reduction of the temperature of the preheated combustion air used in the system and thereby reduces the adiabatic flame temperature. Also, the overall high efficiency of the furnace is generally maintained for the same overall duty with lower intrinsic NOx emissions.

To facilitate a better understanding of the present invention, the following example of certain aspects of some embodiments is given. In no way should the following example be read to limit, or define, the scope of the invention.

EXAMPLE

A conventional fired heater unit utilizing preheated combustion air (case 1) was compared to a fired heater unit of the present invention, in which the radiant section of the fired heater was coated with a high emissivity ceramic coating of the present invention (case 2). Methane (CH₄) fuel was fed at a rate of 1604 pounds per hour (lbs/hr) to each fired heater unit with 10 percent (%) excess air. The effects of radiant efficiency on adiabatic flame temperature and NOx emissions for each case are outlined in Table 1 below, where T₀ is the temperature in °F. of the preheated combustion air stream.
entering the burner, \( T_{ad} \) is the adiabatic flame temperature in °F, \( T_r \) is the temperature in °F. of the radiant section, radiant duty is the heat duty in one million British thermal units per hour (MMBtu/hr) of the radiant section, radiant eff is the percent efficiency of the radiant section based on the combustion air preheat temperature, \( T_c \) is the temperature in °F. of the convection section, convection duty is the heat duty in MMBtu/hr of the convection section, \( T_f \) is the temperature in °F. of the flue gas exiting the fired heater; NOx conv is the NOx concentration in parts per million, volumetric dry (ppmv) for conventional burners, and NOx low is the NOx concentration in ppmvd for low NOx burners.

**Table I**

<table>
<thead>
<tr>
<th>Case</th>
<th>( T_r ) (°F)</th>
<th>( T_{ad} ) (°F)</th>
<th>( T_c ) (°F)</th>
<th>Radiant Duty (MMBtu/hr)</th>
<th>Radiant Eff (%)</th>
<th>Convection Duty (MMBtu/hr)</th>
<th>( T_f ) (°F)</th>
<th>NOx Conv (ppmvd)</th>
<th>NOx Low (ppmvd)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>600</td>
<td>3835</td>
<td>1500</td>
<td>25.3</td>
<td>65.5</td>
<td>780</td>
<td>6.9</td>
<td>344</td>
<td>420</td>
</tr>
<tr>
<td>2</td>
<td>500</td>
<td>3768</td>
<td>1426</td>
<td>25.3</td>
<td>67.2</td>
<td>698</td>
<td>6.9</td>
<td>344</td>
<td>320</td>
</tr>
</tbody>
</table>

As shown in Table I above, the temperature \( T_r \) of the preheated combustion air stream can be lowered by 100° F, in case 2 by increasing the radiant efficiency to 67.2%, while still having the same radiant duty in both cases. In addition, the adiabatic flame temperature \( T_{ad} \) is reduced to 3768° F. by the lower temperature \( T_r \) of the preheated combustion air stream, which will reduce the NOx concentration in the exiting flue gas by approximately about 24% for conventional burners, and about 33% for low NOx burners. In conclusion, the fired heater units of the present invention lower NOx emissions over conventional fired heater units due to the lower adiabatic flame temperature \( T_{ad} \).

Therefore, the present invention is well adapted to attain the ends and advantages mentioned as well as those that are inherent therein. The particular embodiments disclosed above are illustrative only, as the present invention may be modified and practiced in different but equivalent manners apparent to those skilled in the art having the benefit of the teachings herein. While numerous changes may be made by those skilled in the art, such changes are encompassed within the spirit of this invention as defined by the appended claims. Furthermore, no limitations are intended to the details of construction or design herein shown, other than as described in the claims below. It is therefore evident that the particular illustrative embodiments disclosed above may be altered or modified and all such variations are considered within the scope and spirit of the present invention. The terms in the claims have their plain, ordinary meaning unless otherwise explicitly and clearly defined by the patentee.

What is claimed is:

1. A fired heater unit having a first end and a second end, the fired heater unit comprising:
   - a burner at the first end for mixing a fuel stream and a preheated combustion air stream to produce a first flue gas stream;
   - a radiant section operatively connected to the burner, wherein the radiant section includes a high emissivity coating on at least one interior wall of the radiant section, wherein the radiant section is configured to transfer heat by radiant heat transfer from the first flue gas stream to a first process stream to produce a second flue gas stream and a first heated process stream;
   - a convection section operatively connected to the radiant section, wherein the convection section is configured to transfer heat by convection from the second flue gas stream to a second process stream to produce a third flue gas stream and a second heated process stream; and
   - a plenum operatively coupled to the convection section and the second end, wherein a preheater unit is operatively coupled to the convection section and the second end, wherein the preheater unit transfers heat from the third flue gas stream to an ambient air stream to produce a flue gas stream for venting through the second end and the preheated combustion air stream.

2. The fired heater unit of claim 1, wherein the high emissivity coating is a ceramic material comprising small particles of one or more inorganic materials.

3. The fired heater unit of claim 2, wherein the inorganic materials are selected from the group consisting of: silicon, aluminum, iron, titanium, sodium, potassium, calcium, magnesium, zirconium, and boron.

4. The fired heater unit of claim 1, further comprising a forced draft blower that supplies the ambient air stream to the preheater unit.

5. The fired heater unit of claim 1, further comprising an induced draft fan to pull the flue gas stream for venting to atmosphere.

6. The fired heater unit of claim 1, comprising a flow path from the first end to the second end, wherein the flue gas streams flow along the flow path from the first end to the second end.

7. The fired heater unit of claim 1, wherein the second end is open such that the flue gas stream for venting exits the fired heater unit through the second end.

8. A process for reducing NOx emissions from a fired heater unit, the process comprising:
   - mixing a fuel stream and a preheated air stream in a burner to produce a flue gas stream;
   - flowing the flue gas stream to a radiant section of the fired heater unit to heat by radiant heat transfer a first process stream to produce a first heated process stream, wherein the radiant section includes a high emissivity coating for increasing efficiency on at least one interior wall of the radiant section;
   - flowing the flue gas stream to a convection section operatively connected to the radiant section to heat by convection a second process stream to produce a second heated process stream;
   - flowing the flue gas stream to a preheater unit in a plenum operatively coupled to the convection section to heat an ambient air stream to produce the preheated air stream to the burner; and
   - venting the flue gas stream to atmosphere.
9. The process of claim 8, wherein the high emissivity coating is a ceramic material comprising small particles of one or more inorganic materials.

10. The process of claim 9, wherein the inorganic materials are selected from the group consisting of: silicon, aluminum, iron, titanium, sodium, potassium, calcium, magnesium, zirconium, and boron.

11. The process of claim 8, further comprising supplying the ambient air stream to the preheater unit with a forced draft fan.

12. The process of claim 8, further comprising venting the flue gas to atmosphere with an induced draft fan.