SYSTEM AND METHOD FOR COMBUSTING AMMONIA

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present application claims priority to U.S. Provisional Application 63/568,258 filed March 21, 2024, which is incorporated by reference herein.

BACKGROUND OF THE INVENTION

[0002] The combustion of ammonia presents a series of challenges compared to more traditional fuels such as hydrocarbons or hydrogen. Ammonia is more difficult to ignite, with a minimum ignition energy of around 680 MJ compared with 0.3 MJ for methane. Hydrogen has an even lower ignition energy of 0.2 MJ, which is why it can ignite from the frictional energy generated in a pipe leak. Furthermore, the flammability limit of ammonia in air ranges from 15% to 28% on a volume basis (all percentages herein will be on a volume basis unless stated otherwise) compared to 5-15% for methane and 4.7-75% for hydrogen, which underscores the need for proper mixing of fuel and oxidant for ammonia combustion. The lean blowoff velocity for ammonia of 0.7 m/s is much lower than methane (0.38 m/s) or hydrogen (3.5 m/s), so the ammonia flame itself is less stable with a slow reaction rate. Once the flame is established, the flame temperature of ammonia of 1700 °C is lower than methane (1875 °C) or hydrogen (2045 °C) which reduces the heat transfer rate to the furnace load. Despite the lower flame temperature and slower reaction rate, the relative NOx emissions for an ammonia flame will be higher than methane or hydrogen flames since ammonia is the principal pathway through which most fuel NOx is formed.

SUMMARY OF THE INVENTION

[0003] A method comprising: heating a refractory surface in a combustion chamber to produce a heated refractory surface; contacting a stream comprising ammonia with the heated refractory surface to dissociate at least a portion of the ammonia to form nitrogen and hydrogen and produce an at least partially dissociated ammonia stream; and combusting at least a portion of the at least partially dissociated ammonia stream with a primary oxidant to produce an at least partially combusted ammonia stream.

[0004] An ammonia burner comprising: a combustion chamber comprising a refractory lining surrounding at least a portion of the central combustion channel, a primary oxidant inlet configured to deliver a primary oxidant in an axial direction and an ammonia inlet configured to deliver ammonia with a tangential velocity to contact the refractory lining.

BRIEF DESCRIPTION OF DRAWINGS

[0005] The present invention will hereinafter be described in conjunction with the appended figures wherein like numerals denote like elements:

[0006] Fig. 1 is a schematic view of a cutaway profile of a burner according to one or more aspects of the present disclosure.

[0007] Fig. 2 is a schematic view depicting a modification of Fig. 1 in which startup fuel is replaced by one or more heating elements.

[0008] Fig. 3 is a cross-sectional side schematic view of a burner with a narrowing cross-section in the direction of flow according to one or more aspects of the present disclosure.

[0009] Fig. 4 is a schematic view of a cutaway profile of a burner with a heat exchanger integrated with a heat sink according to one or more aspects of the present disclosure.

[0010] Fig. 5 is a schematic view depicting a modification of Fig. 4 in which only a portion of an ammonia feed stream is preheated.

[0011] Fig. 6A is a cross-sectional side schematic view of a burner with a cavity embedded into a primary combustor wall according to one or more aspects of the present disclosure.

[0012] Fig. 6B is a cross-sectional side schematic view of the burner of Fig. 6A zoomed in on the cavity.

DETAILED DESCRIPTION OF THE INVENTION

[0013] The ensuing detailed description provides preferred exemplary embodiments only, and is not intended to limit the scope, applicability, or configuration of the invention. Rather, the ensuing detailed description of the preferred exemplary embodiments will provide those skilled in the art with an enabling description for implementing the preferred exemplary embodiments of the invention. Various changes may be made in the function and arrangement of elements without departing from the spirit and scope of the invention, as set forth in the appended claims.

[0014] The present disclosure is directed to a novel burner for combusting ammonia. A surface within the burner is preheated so that ammonia at least partially dissociates on contact with the surface. The resulting mixture of ammonia, nitrogen, and hydrogen is mixed with an oxidant to generate a flame and maintains the temperature of the heated surface.

[0015] The present disclosure is also directed to a method for combusting ammonia using the disclosed burner wherein the method comprises the preheating of a combustor surface prior to ammonia injection. Once ammonia is injected, partial dissociation (cracking) occurs by

contact with the surface, resulting in a mixture of ammonia, nitrogen and hydrogen which is combusted with an oxidant. A portion of the resultant energy release is used to maintain the heated combustor surface, thereby perpetuating the combustion reaction.

[0016] In accordance with the present embodiments, a burner comprises a refractory lining that may be preheated to at least 400 °C, or at least 600 °C, or at least 800 °C. The temperature of the refractory lining may be maintained above the auto-ignition temperature of ammonia. The refractory lining may be preheated using a preheating burner. The preheating burner may comprise an ignitor and/or a flame scanner. The preheating burner may use a startup fuel such as hydrogen or natural gas, and may use an oxidant such as air, oxygen-enriched air, or oxygen. When the refractory lining reaches the desired temperature, ammonia may be fed into the burner at least a portion of the ammonia may contact a surface of the refractory lining where ammonia may be cracked to form nitrogen and hydrogen. The ammonia may be fed into the burner in a tangential direction to induce a swirling flow pattern and increase the contact time with the refractory lining. Swirl vanes may also be placed in the nozzle to increase the radial expansion of the flow pattern and improve contact with the refractory lining. Ammonia may be fed into the burner via the same inlet passage as the startup fuel. The flow rate of the startup fuel may be decreased as the flow rate of ammonia increases; the temperature in the burner may be measured to confirm ammonia combustion. At steady-state operation the ammonia may contribute at least 90% of the total heating value of the fuel entering the burner. At steady-state operation the flow rate of startup fuel may be zero, in which case the ammonia may contribute 100% of the total heating value in the burner. During conditions requiring more flame stability, such as turn-down, the flow rate of startup fuel may be restarted or increased, and/or a flow rate of oxygen may be introduced or increased.

[0017] The refractory lining may also be preheated by embedding one or more heating elements, such as electric heating elements. The one or more heating elements may be used to replace or enhance preheating by a preheating burner.

[0018] The refractory lining may comprise a castable material such as alumina. The refractory lining may comprise on or more bricks. The refractory lining may comprise a catalytic material such as nickel to catalyze the cracking reaction to convert ammonia to nitrogen and hydrogen. The refractory lining may vary in cross section by decreasing along the direction of flow in order to reduce radiant heat loss in the upstream section by minimizing the “shape” or “view” factor between the combustor and an exit plane of the burner. The refractory lining may have a first inner diameter in a primary combustion zone and a second inner diameter in a zone downstream of the combustion zone, wherein the first inner diameter is greater than the

second inner diameter. Downstream refers to the intended flow direction of the gases in the burner, in that the gases flow from the location of the first inner diameter to the location of the second inner diameter. The refractory lining may have a section with a greater cross-sectional area to create a wall cavity that may generate recirculation flow and increase the residence time of gases "trapped" within the cavity. The refractory lining in the wall cavity section may comprise a catalytic material.

[0019] The refractory lining may also comprise a heat exchange surface such as heat transfer coils embedded within the refractory lining. The heat exchange surface may be used to preheat at least a portion of the ammonia. In cases where a portion of the ammonia is preheated, the preheated ammonia and unpreheated ammonia may be fed to the burner by separate passages. A secondary oxidant which may comprise air, oxygen-enriched air, or oxygen, may be added to the preheated ammonia stream prior to injection into the burner. The secondary oxidant may have an oxygen concentration of at least 30% on a molar basis.

[0020] A person of skill in the art will appreciate that the features of the refractory lining listed above may be used in any combination as deemed appropriate for a given application.

[0021] NOx emissions may be reduced by operating with a fuel-rich equivalence ratio in a primary combustion chamber of the burner greater than 1.0, with staged air injection downstream of the primary combustion chamber to complete the combustion reactions.

[0022] Fig. 1 is a schematic view of a cutaway profile of a burner according to one or more aspects of the present disclosure. A central channel 11 may deliver a startup fuel 13 such as hydrogen and/or methane. The central channel may also comprise a flame scanner 15 to monitor the stability of the flame. A second channel 21 surrounds the central channel 11 and may deliver a primary oxidant 23 such as air, enriched-oxygen air, or oxygen. An ignitor 25 may be positioned radially outward from the second channel 21. A flame may be generated in a combustion chamber 31 surrounded by a refractory lining 33, preheating the refractory lining 33 to a desired temperature. When the refractory lining 33 is at or above the desired temperature, ammonia 35 may be injected into the combustion chamber 31. In Fig. 1 the ammonia 35 is added to the combustion chamber 31 in a tangential direction to produce a swirling flow that pushes the ammonia 35 to the outside of the combustion chamber 31 where it makes better contact with the refractory lining 33. Once the ammonia 35 has at least partially dissociated due to contact with the refractory lining 33, it may combust. Ammonia combustion may be detected as an increase in temperature in the refractory lining 33. Once ammonia combustion has occurred, the flow rate of startup fuel 13 may be decreased or stopped. In typical burners with multiple channels, the outermost channel delivers an oxidant or inert gas to protect the walls of the combustion chamber from high temperatures and/or reactions such

as coking reactions. However, the relatively low combustion temperature of ammonia allows combustion to take place in direct contact with the refractory lining 33 without damaging the material, hence delivering ammonia 35 in between the primary oxidant 23 and the refractory lining 33. The fuel equivalence ratio, defined as the ratio of the fuel to oxidant ratio to the stoichiometric ratio, may be maintained fuel-rich in the combustion chamber 31 to reduce NOx formation. A fuel-rich equivalence ratio is any ratio greater than 1.0. A secondary oxidant 37 may be fed through an outer channel to complete combustion downstream of the combustion chamber 31. In the case of Fig. 1, the secondary oxidant 37 is air.

[0023] Fig. 2 is a schematic view depicting a modification of Fig. 1 in which startup fuel 13 is replaced by one or more heating elements 217. In this case the heating elements are electrically powered. This arrangement may be preferable when emissions from a startup burner must be avoided.

[0024] Fig. 3 is a cross-sectional side schematic view of a burner with a narrowing cross-section in the direction of flow 341. The smaller cross section at the burner exit plane 343 reduces the paths that the refractory lining may radiate heat out of the combustion chamber, reducing heat losses. The section of the combustion chamber 331 upstream of the narrowing cross-section is defined as a primary combustion zone.

[0025] Fig. 4 is a schematic view of a cutaway profile of a burner with a heat exchanger integrated with a heat sink. The narrowing combustion chamber of Fig. 3 is also used in this arrangement. Note that unlike in Fig. 1, the central channel 411 delivers the primary oxidant 423 and the second channel 421 delivers the startup fuel 413. Ammonia 35 is preheated by traveling through a heat exchanger coil 439 embedded within the refractory lining 33 before entering the second channel 421. The nozzle entering the combustion chamber may have one or more swirl vanes 441 to impart a tangential velocity and improve contact of the ammonia 35 with the refractory lining 33. Secondary oxidant 37 may exit the burner via port 449 to allow complete combustion downstream of the combustion chamber, for example in the case where the combustion chamber is operated fuel-rich.

[0026] Fig. 5 is a schematic view depicting a modification of Fig. 4 in which only a portion of an ammonia feed stream is preheated. The central channel 411 delivers the primary oxidant 423 as in Fig. 4. The unheated ammonia may enter the second channel 521 with the startup fuel. The preheated ammonia may enter a third channel 551 surrounding the second channel. The third channel may also deliver a secondary oxidant, such as air, enriched-oxygen air, and oxygen.

[0027] Fig. 6A is a cross-sectional side schematic view of a burner with a cavity embedded into a primary combustor wall. As in Fig. 4, central channel 411 delivers the primary oxidant

423. Second channel 621 may deliver an optional secondary oxidant. A recirculation flow pattern effectively traps a portion of the ammonia, increasing the residence time for ammonia cracking. To improve the efficiency of catalyst use, an increased amount of catalyst may be applied to the cavity walls. In at least some embodiments, the only portion of the refractory lining that is treated with catalyst is in the cavity section 661.

[0028] Fig. 6B is a cross-sectional side schematic view of the burner of Fig. 6A zoomed in on the cavity. The recirculation flow pattern 671 can be seen diverging from the portion of the flow traveling in the axial direction 673.

[0029] Aspect 1: A method comprising heating a refractory surface in a combustion chamber to produce a heated refractory surface; contacting a stream comprising ammonia with the heated refractory surface to dissociate at least a portion of the ammonia to form nitrogen and hydrogen and produce an at least partially dissociated ammonia stream; and combusting at least a portion of the at least partially dissociated ammonia stream with a primary oxidant to produce an at least partially combusted ammonia stream.

[0030] Aspect 2: A method according to Aspect 1, wherein the refractory surface comprises a catalyst to promote the reaction rate of the dissociation of ammonia.

[0031] Aspect 3: A method according to any of Aspects 1 or 2, wherein the refractory surface is heated by combustion of a preheating fuel within the ammonia burner.

[0032] Aspect 4: A method according to any of Aspects 1 to 3, wherein the stream comprising ammonia is fed into the combustion chamber with a tangential velocity to improve contact with the heated refractory surface.

[0033] Aspect 5: A method according to any of Aspects 1 to 4, wherein a fuel equivalence ratio in the combustion chamber is greater than 1.0.

[0034] Aspect 6: A method according to any of Aspects 1 to 5, further comprising reacting the at least partially combusted ammonia stream with a secondary oxidant downstream of the combustion chamber.

[0035] Aspect 7: A method according to any of Aspects 1 to 6, wherein the stream comprising ammonia contacts a cavity in the heated refractory surface to induce a recirculation flow pattern in the cavity.

[0036] Aspect 8: A method according to any of Aspects 1 to 7, further comprising preheating at least a portion of the stream comprising ammonia by indirect heat exchange with the heated refractory surface prior to entering the ammonia burner.

[0037] Aspect 9: An ammonia burner comprising a combustion chamber comprising a refractory lining surrounding at least a portion of the central combustion channel, a primary oxidant inlet configured to deliver a primary oxidant in an axial direction and an ammonia inlet configured to deliver ammonia with a tangential velocity to contact the refractory lining.

[0038] Aspect 10: An ammonia burner according to Aspect 9, wherein the ammonia burner comprises a secondary oxidant inlet configured to deliver a secondary oxidant downstream of the combustion chamber.

[0039] Aspect 11: An ammonia burner according to Aspects 9 or 10, wherein the combustion chamber comprises a start-up fuel inlet positioned concentrically within the primary oxidant inlet.

[0040] Aspect 12: An ammonia burner according to any of Aspects 9 to 11, wherein the combustion chamber comprises a cavity with an increased inner diameter configured to generate a recirculation flow pattern within the cavity.

[0041] Aspect 13: An ammonia burner according to any of Aspects 9 to 12, wherein the combustion chamber comprises a primary combustion zone with a first inner diameter and a zone downstream of the primary combustion zone with a second inner diameter, wherein the first inner diameter is larger than the second inner diameter.

[0042] Aspect 14: An ammonia burner according to any of Aspects 9 to 13, wherein the refractory lining comprises a catalyst configured to promote the dissociation of ammonia.

[0043] Aspect 15: An ammonia burner according to any of Aspects 9 to 14, wherein the refractory lining comprises a heat exchanger in fluid flow communication with the ammonia inlet.

[0044] While the principles of the invention have been described above in connection with preferred embodiments, it is to be clearly understood that this description is made only by way of example and not as a limitation of the scope of the invention.

CLAIMS

1. A method comprising:

heating a refractory surface in a combustion chamber to produce a heated refractory surface;

contacting a stream comprising ammonia with the heated refractory surface to dissociate at least a portion of the ammonia to form nitrogen and hydrogen and produce an at least partially dissociated ammonia stream; and

combusting at least a portion of the at least partially dissociated ammonia stream with a primary oxidant to produce an at least partially combusted ammonia stream.

2. The method of Claim 1, wherein the refractory surface comprises a catalyst to promote the reaction rate of the dissociation of ammonia.

3. The method of Claim 1, wherein the refractory surface is heated by combustion of a preheating fuel within the ammonia burner.

4. The method of Claim 1, wherein the stream comprising ammonia is fed into the combustion chamber with a tangential velocity to improve contact with the heated refractory surface.

5. The method of Claim 1, wherein a fuel equivalence ratio in the combustion chamber is greater than 1.0.

6. The method of Claim 5, further comprising reacting the at least partially combusted ammonia stream with a secondary oxidant downstream of the combustion chamber.

7. The method of Claim 1, wherein the stream comprising ammonia contacts a cavity in the heated refractory surface to induce a recirculation flow pattern in the cavity.

8. The method of Claim 1, further comprising preheating at least a portion of the stream comprising ammonia by indirect heat exchange with the heated refractory surface prior to entering the ammonia burner.

9. An ammonia burner comprising:

a combustion chamber comprising a refractory lining surrounding at least a portion of the central combustion channel, a primary oxidant inlet configured to deliver a primary oxidant in an axial direction and an ammonia inlet configured to deliver ammonia with a tangential velocity to contact the refractory lining.

10. The ammonia burner of Claim 9, wherein the ammonia burner comprises a secondary oxidant inlet configured to deliver a secondary oxidant downstream of the combustion chamber.

11. The ammonia burner of Claim 9, wherein the combustion chamber comprises a start-up fuel inlet positioned concentrically within the primary oxidant inlet.

12. The ammonia burner of Claim 9, wherein the combustion chamber comprises a cavity with an increased inner diameter configured to generate a recirculation flow pattern within the cavity.

13. The ammonia burner of Claim 9, wherein the combustion chamber comprises a primary combustion zone with a first inner diameter and a zone downstream of the primary combustion zone with a second inner diameter, wherein the first inner diameter is larger than the second inner diameter.

14. The ammonia burner of Claim 9, wherein the refractory lining comprises a catalyst configured to promote the dissociation of ammonia.

15. The ammonia burner of Claim 9, wherein the refractory lining comprises a heat exchanger in fluid flow communication with the ammonia inlet.