CLAIMS

1. Process for producing hydrogen by thermal reforming of ammonia in an apparatus comprising an ammonia cracking reactor with a catalyst chamber and a staged combustion unit, wherein the catalyst chamber of the ammonia cracking reactor is heated indirectly by heat exchange with flue gases from the staged combustion unit, comprising the steps of:
a) incomplete combustion of a fuel comprising ammonia in a first stage of the staged combustion unit with a first oxygen-containing stream to generate a first flue gas stream of elevated temperature T1 in the range of 750 to 2000°C, preferably in the range of 1200 to 2000°C;
b) complete combustion of the fuel comprising ammonia by further combustion of the first flue gas stream in the second stage of the staged combustion unit with a second oxygen-containing stream to generate a second flue gas stream of a temperature T3 that is less than T1;
c) exchanging heat from the second flue gas stream provided in step b) with the ammonia cracking reactor to raise the temperature in the catalyst chamber to a catalytic cracking temperature T2 in the range of 400 to 1000°C, more preferably in the range of 600 to 800°C;
d) subjecting an ammonia containing stream in the ammonia cracking reactor heated in step c) to a catalytic ammonia-cracking step to yield a thermally cracked stream comprising hydrogen, and
e) separating the thermally cracked stream into a reject gas stream and an enriched hydrogen stream and withdrawing the enriched hydrogen stream,
wherein T3 is at least 50°C above T2 and wherein T3 is up to a maximum of 1600°C, and wherein T3 is at least 50°C below T1, wherein the reject gas stream of step e) is recycled to the first stage of the staged combustion unit and wherein the fuel in step a) consists of ammonia and the reject gas stream of step e).

2. The process of claim 1, wherein the fuel is combusted in the first stage of the staged combustion unit with a sub-stoichiometric amount of oxygen, preferably supplied as air, and downstream in the second stage of the staged combustion unit with a surplus amount of oxygen, preferably supplied as air.

3. The process of any one of claims 1-2, wherein ammonia is combusted in the first stage of the combustion unit up to a residual ammonia content that is more than zero and less than 1000 ppm, preferably less than 100 ppm, more preferably less than 50 ppm.

4. The process of any one of claims 1-3, wherein T3 is at least 100°C above T2 and wherein T3 is up to a maximum of 1200°C and/or wherein T3 is at least 100°C below T1, more preferably wherein T3 is at least 200°C below T1.

5. The process of any one of claims 1-4, wherein the sub-stoichiometric amount of oxygen used in the first stage of the combustion unit is 80 to less than 100% and preferably 90 to 99%, more preferably 95 to 98% of the stoichiometric amount.

6. The process of any one of claims 1-5, wherein the combustion in the first stage of the combustion unit is performed at a temperature in the range of 1500-1800°C.

7. The process of any one of claims 1-6, wherein the combustion in the second stage of the combustion unit is performed at a temperature in the range of 700-1200°C, preferably in the range of 750-1150°C, more preferably in the range of 800-1100°C.

8. The process of any one of claims 1-7, wherein the first oxygen-containing stream, preferably air, has a temperature in the range of 20-500°C.

9. The process of any one of claims 1-8, wherein the second oxygen-containing stream, preferably air, has a temperature in the range of 20-500°C.

10. The process of any one of claims 1-9, wherein a quench fluid is added to the second stage of the combustion unit.

11. An apparatus (1) for producing hydrogen by thermal reforming of ammonia, comprising

(i) a staged combustion unit (2) with a first stage unit (2A) configured for partial incomplete combustion of fuel comprising ammonia with an inlet (21) for fuel and an inlet (22) for a first oxygen-containing stream and an integrated outlet/inlet (23) for a first flue gas stream of elevated temperature T1 in the range of 750-2000°C, and a second stage unit (2B) connected to the integrated outlet/inlet (23) and configured for complete combustion of the fuel by further combustion of the first flue gas stream with an inlet (24) for a second oxygen-containing stream and an integrated outlet/inlet (25) for a second flue gas stream of a temperature T3 that is less than T1, and

(ii) an ammonia cracking reactor (3) with a catalyst chamber (36), wherein reactor (3) is connected to outlet/inlet (25) of the staged combustion unit and configured for heat exchange with the second flue gas stream from the staged combustion unit to raise the temperature in the catalyst chamber (36) to a catalytic cracking temperature T2 in the range of 400-1000°C, wherein reactor (3) is further provided with an outlet (33) for a third flue gas after exchange of heat, and wherein the catalyst chamber (36) is provided with an inlet (31) for an ammonia stream and provided with an outlet (32) for a thermally cracked stream comprising hydrogen, and

(iii) a hydrogen separation unit (4) configured for separating the thermally cracked stream into a reject gas stream, wherein the reject gases may be recirculated through line (42) to the burner (10), and an enriched hydrogen stream and withdrawing the enriched hydrogen stream;

wherein T3 is at least 50°C above T2 up to a maximum of 1600°C, and wherein T3 is at least 50°C below T1, wherein the reject gas stream is recycled to the first stage unit(2A) of the staged combustion unit (2) and wherein the fuel in the first stage unit (2A) consists of ammonia and the reject gas stream.

12. The apparatus (1) of claim 11, wherein the second stage unit (2B) comprises a further inlet for a quench fluid.

13. The apparatus (1) of claim 11, wherein the ammonia cracking reactor (3) is in the form of a bayonet type reactor, wherein the outlet (32) for the thermally cracked stream comprising hydrogen is connected to an inner pipe (37) that is passing through the catalyst chamber (36).

14. The apparatus (1) of any one of claims 11-12, wherein the hydrogen separation unit (4) is a PSA.

15. The apparatus (1) of any one of claims 11-13, further comprising a unit (5) to remove NOx.