CO rich synthesis gas streams are used for a variety of applications, including the production of methanol and synthetic fuels (e.g. jet fuel, kerosene, diesel, and/or gasoline) via for example the Fischer-Tropsch route.

WO2020/174057 discloses synthesis gas production by steam methane reforming.

Heat exchange reforming in connection with synthesis gas production from a natural gas-based feedstock is well known. In this case a heat exchange reformer is placed either in series or in parallel with a main steam reformer such as steam methane reformer and/or an autothermal reformer. A main issue in such schemes is metal dusting especially when synthesis gas stream with a high content of carbon monoxide is required. In the present invention, this issue is significantly reduced.

SUMMARY

It has been found that the disadvantages of known systems/processes for CO_2 shift can be reduced, and even completely avoided using the system/process provided herein. Also, it has surprisingly been found that the using a HER type reactor for CO_2 shift in contrast to a heat exchange steam methane reformer is a much more robust solution. Also, the HER type reactor for CO_2 shift has been found to process significantly larger quantities of feedstock compared to a heat exchange steam methane reformer. Also, surprisingly the HER type reactor for CO_2 shift has been found to have a much lower risk of metal dusting compared to a heat exchange steam methane reformer.

In one aspect of the present disclosure, there is provided a system for CO_2 shift, said system comprising:

- a first feed comprising CO_2 and H_2,
- a second feed comprising CO_2 and H_2,
- a Reverse Water Gas Shift (RWGS) reactor, and
- a heat exchange reactor, HER having at least a process side and at least a heating side,

wherein the first feed is arranged to be fed to the RWGS reactor and converted into a first product stream comprising CO;

wherein the second feed is arranged to be fed to a process side of the HER;

wherein at least a portion of the first product stream is arranged to be fed to a heating side of the HER such that heat from the first product stream is transferred to the process side of the HER, thereby allowing the conversion of the second feed to a second product stream comprising CO in the process side of the HER; and providing a cooled first product stream.

In another aspect of the present disclosure, there is provided a process for CO_2 shift, in a system according to any one of the preceding claims, said process comprising the steps of:

- feeding the first feed comprising CO_2 and H_2 to the RWGS reactor and converting it into a first product stream comprising CO;
- feeding the second feed comprising CO_2 and H_2 to the process side of the HER;
- arranging at least a portion of the first product stream to be fed to the heating side of the HER such that heat from the first product stream is transferred to the process side of the HER, thereby allowing the conversion of the second feed to a second product stream comprising CO in the process side of the HER; thus providing a cooled first product stream.

In a further aspect of the present disclosure, there is provided a method for starting up the process disclosed herein, wherein the RWGS reactor is an electrical Reverse Water Gas Shift (e-RWGS) reactor, said method comprising the steps of:

a) introducing said first feed comprising CO_2 and H_2, to said RWGS reactor and converting it into a first product stream comprising CO; and allowing said at least a portion of the first product stream to be fed to the heating side of the HER;
b) increasing the temperature of said first product stream by increasing the electrical power to said e-RWGS reactor;
c) feeding said second feed comprising CO_2 and H_2, to the process side of the HER wherein steps b and c are carried out after step a.

In one example, therefore a system for CO_2 shift is provided. The system comprises:

- a first feed comprising CO_2 and H_2,
- a second feed comprising CO_2 and H_2,
- a Reverse Water Gas Shift (RWGS) reactor, and
- a heat exchange reactor, HER having at least a process side and at least a heating side,

The first feed is arranged to be fed to the RWGS reactor and converted into a first product stream comprising CO. The second feed is arranged to be fed to the process side of the HER.

At least a portion of the first product stream is arranged to be fed to the heating side of the HER such that heat from the first product stream is transferred to the process side of the HER. Conversion of the second feed to a second product stream comprising CO in the process side of the HER is thereby allowed. A cooled first product stream results.

CLAIMS

1. A system for CO_2 shift, said system comprising:

- a first feed comprising CO_2 and H_2,
- a second feed comprising CO_2 and H_2,
- a Reverse Water Gas Shift (RWGS) reactor, and
- a heat exchange reactor, HER having at least a process side and at least a heating side,

wherein the first feed is arranged to be fed to the RWGS reactor and converted into a first product stream comprising CO;

wherein the second feed is arranged to be fed to a process side of the HER;

wherein at least a portion of the first product stream is arranged to be fed to a heating side of the HER such that heat from the first product stream is transferred to the process side of the HER, thereby allowing the conversion of the second feed to a second product stream comprising CO in the process side of the HER; and providing a cooled first product stream.

2. The system according to claim 1, wherein the RWGS reactor is selected from an electrical RWGS (e-RWGS) reactor, a fired RWGS reactor or an autothermal RWGS reactor, preferably an electrical RWGS (e-RWGS) reactor.

3. The system according to any one of the preceding claims, wherein the first and/or second feed comprises methane, wherein the first and/or second feed comprises up to 3 mole%, or up to 8 mole%, or up to 12 mole% methane.

4. The system according to any one of the preceding claims, wherein the methane content in the first feed is higher than the methane content in the second feed, preferably wherein the molar content of methane in the second stream relative to the molar content of methane in the first feed is 0, or below 0.1 or below 0.5.

5. The system according to any one of the preceding claims, further comprising a primary feed comprising CO_2 and H_2, wherein said primary feed is arranged to be divided into at least said first feed comprising CO_2 and H_2, and said second feed comprising CO_2 and H_2.

6. The system according to any one of the preceding claims, wherein the HER is a bayonet-type HER, and wherein at least a portion of the second product stream is arranged to be fed to the heating side of the HER to provide a second cooled product stream.

7. The system according to any one of claims 1-5, wherein at least a portion of the second product stream is arranged to be fed to the heating side of the HER, in admixture with part or all of the first product stream, and whereby said HER is arranged to output a third product stream from the heating side thereof.

8. The system according to any one of the preceding claims, further comprising a combustion unit and a third feed of fuel, wherein said third feed of fuel is arranged to be fed to the combustion unit and combusted therein in the presence of an oxidant to provide a fifth feed of combusted gas, wherein said fifth feed is arranged to be fed to the heating side of the HER, alone or in admixture with said first and/or said second product streams.

9. The system according to claim 8, wherein the oxidant in said combustion unit is substantially pure oxygen.

10. The system according to any one of claims 8 - 9, wherein the third feed of fuel is a feed comprising hydrogen, and the fifth feed is feed comprising steam.

11. The system according to any one of claims 8 - 9, wherein the third feed of fuel is a feed comprising methane, and the fifth feed is a feed comprising carbon dioxide and steam.

12. The system according to claim 11, wherein the cooled fifth feed is used downstream the HER as part of said first feed comprising CO_2 and H_2 and/or as part of said second feed comprising CO_2 and H_2.

13. The system according to any one of the preceding claims, wherein the process side of the HER comprises a process side inlet and a process side outlet, wherein a first reaction zone (I) is disposed closest to the process side inlet,
and a second reaction zone (II) is disposed closest to the process side outlet,
wherein the first reaction zone (I) is arranged to carry out an overall exothermic reaction of said second feed, wherein the overall exothermic reaction comprises at least the following reactions, which have a net progress from left to right:

$$CO\ (g) + 3\ H_2\ (g) \leftrightarrows CH_4\ (g) + H_2O\ (g) \qquad (2)$$

$$CO_2\ (g) + H_2\ (g) \leftrightarrows CO\ (g) + H_2O\ (g) \qquad (1),$$

wherein the second reaction zone (II) is arranged to carry out an overall endothermic reaction, wherein the overall endothermic reaction comprises at least the following reactions, which have a net progress from left to right:

CH_4 (g) + H_2O ⇆ CO (g) + $3H_2$ (g) (reverse of)

CO_2 (g) + H_2 (g) ⇆ CO (g) + H_2O (g) (1).

14. The system according to claim 13, wherein the process side of the HER has a total length extending from the process side inlet to the process side outlet, and wherein the first reaction zone (I) has an extension of less than 50%, such as less than 30%, preferably less than 20%, more preferably less than 10% of the total length of the process side of the HER.

15. The system according to any one of claims 13-14, wherein a first catalyst is located at least in the first reaction zone (I).

16. The system according to any one of claims 13-15, wherein at least the end of the first reaction zone (I) which is located closest to the inlet of the HER is not directly in contact with the heating side of the HER, so that this end of the first reaction zone (I) is primarily heated by the adiabatic temperature rise caused by said exothermic reaction.

17. The system according to any one of the preceding claims, wherein the RWGS reactor is an electrical Reverse Water Gas Shift (e-RWGS) reactor or a fired RWGS reactor and wherein the HER is arranged to produce more than 20%, more than 30%, or more than 40%, or more than 50% or more than 60% of the total combined CO produced by the RWGS reactor and the HER.

18. The system according to any one of the preceding claims, wherein the RWGS reactor is an electrical Reverse Water Gas Shift (e-RWGS) reactor or a fired RWGS reactor and wherein the system is arranged such that the molar flow of the second feed constitutes more than 20%, more than 30%, or more than 40%, or more than 50% or more than 60% of the total combined molar flow of the first and second feeds.

19. The system according to any one of the preceding claims, wherein the RWGS reactor is an electrical Reverse Water Gas Shift (e-RWGS) reactor or a fired RWGS reactor and wherein the system is arranged such that the molar carbon flow of the second feed constitutes more than 20%, more than 30%, or more than 40%, or more than 50% or more than 60% of the total combined molar carbon flow of the first and second feeds.

20. A process for CO_2 shift, in a system according to any one of the preceding claims, said process comprising the steps of:

- feeding the first feed comprising CO_2 and H_2 to the RWGS reactor and converting it into a first product stream comprising CO;
- feeding the second feed comprising CO_2 and H_2 to the process side of the HER;
- arranging at least a portion of the first product stream to be fed to the heating side of the HER such that heat from the first product stream is transferred to the process side of the HER, thereby allowing the conversion of the second feed to a second product stream comprising CO in the process side of the HER; thus providing a cooled first product stream.

21. The process according to claim 20, wherein the RWGS reactor is selected from an electrical Reverse Water Gas Shift (e-RWGS) reactor, a fired RWGS reactor or an autothermal RWGS reactor.

22. The process according to any one of claims 20-21, wherein the RWGS reactor is an electrical Reverse Water Gas Shift (e-RWGS) reactor or a fired RWGS reactor and wherein more than 20%, more than 30%, or more than 40%, or more than 50% or more than 60% of the total combined duty from the RWGS reactor and the HER can be placed in the HER.

23. The process according to any one of claims 20-22, wherein the RWGS reactor is an electrical Reverse Water Gas Shift (e-RWGS) reactor or a fired RWGS reactor and wherein the HER produces more than 20%, more than 30%, or more than 40%, or more than 50% or more than 60% of the total combined CO produced by the RWGS reactor and the HER.

24. The process according to any one of claims 20-23, wherein the RWGS reactor is an electrical Reverse Water Gas Shift (e-RWGS) reactor or a fired RWGS reactor and wherein the molar flow of the second feed constitutes more than 20%, more than 30%, or more than 40%, or more than 50% or more than 60% of the total combined molar flow of the first and second feeds.

25. The process according to any one of claims 20-24, wherein the RWGS reactor is an electrical Reverse Water Gas Shift (e-RWGS) reactor or a fired RWGS reactor and wherein the molar carbon flow of the second feed constitutes more than 20%, more than 30%, or more than 40%, or more than 50% or more than 60% of the total combined molar carbon flow of the first and second feeds.

26. The process according to any one of claims 20-25, wherein the process conditions are adjusted to provide a temperature of the cooled first product stream and/or the cooled second product stream and/or the cooled third product stream at the outlet of the HER which is higher than the critical limit for metal dusting.

27. The process according to any one of claims 20-26, wherein the cooled exit temperature of the cooled first product stream and/or cooled second product stream and/or the cooled third product stream is 500°C or higher, 600°C or higher, 700°C or higher, or 800°C or higher.

28. The process according to any one of claims 20-27, wherein the cooled first product stream and/or the cooled second product stream and/or the cooled third product stream at said cooled exit temperature has a CO reduction reaction actual gas carbon activity lower than 100, or lower than 50, or lower than 10, or lower than 5, or lower than 1.

29. The process according to any of one of claims 20-28, wherein the H_2/CO ratio of the first product gas, the second product gas, and/or the third cooled product stream is in the range from 0.5 to 3.0, such as in the range 1.9 – 2.1, or in the range 2 - 3.

30. The process according to any of one of claims 20-29, wherein the $(H_2-CO_2)/(CO+CO_2)$ ratio of the first product gas, the second product gas, and/or the third cooled product stream is in the range from 1.5 to 2.5, such as in the range 1.9 – 2.1, or in the range 2 – 2.05.

31. A method for starting up the process according to any one of claims 20-30, wherein the RWGS reactor is an electrical Reverse Water Gas Shift (e-RWGS) reactor, said method comprising the steps of:

a) introducing said first feed comprising CO_2 and H_2, to said RWGS reactor and converting it into a first product stream comprising CO; and allowing said at least a portion of the first product stream to be fed to the heating side of the HER;
b) increasing the temperature of said first product stream by increasing the electrical power to said e-RWGS reactor;
c) feeding said second feed comprising CO_2 and H_2, to the process side of the HER wherein steps b and c are carried out after step a.

32. The method according to claim 31, wherein step b) is carried out after step c) or step c) is carried out after step b).

33. The method according to any one of claims 31 – 32 wherein step c) is performed over a time period of 5 hours, preferably 1 hour, and even more preferably 30 min.