

Reformer reactor and method for converting hydrocarbon fuels into hydrogen rich gas

5 The present invention relates to a reformer reactor for converting hydrocarbon fuels into hydrogen rich gas for fuel cells and/or exhaust treatment applications by auto-thermal reaction according to claim 1 and a method for converting hydrocarbon fuels into hydrogen rich gas using the reformer reactor.

10 In the state of the art it is well known to produce hydrogen rich gas for the use in fuels cells of transportation devices by reforming hydrocarbon fuels, like gasoline or diesel fuels. Conventionally, hydrogen is produced in large-scale industrial facilities and then stored on board of the transportation devices. The recent development of small-scale on-board hydrogen sources, so-called reformer reactors, provides a possibility for producing hydrogen on demand without the necessity of
15 hydrogen storage.

In general there are three known methods of reforming gaseous or liquid hydrocarbon fuels into hydrogen: catalytic steam reforming, partial oxidation reforming and auto-thermal reforming.
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In catalytic steam reforming processes a mixture of steam and hydrocarbon fuel is exposed to a suitable catalyst, like nickel, at a high temperature (between 700°C and 1000°C). The reaction is highly endothermic and requires an external source of heat and a source of steam.
25

In partial oxidation reforming processes a mixture hydrogen fuel and an oxygen containing gas, like ambient air, are brought together within a reaction chamber and subjected to an elevated temperature, preferably in the presence of a catalyst. The catalyst used is normally a noble metal or nickel and the temperature is
30 between 700°C and 1700°C. The reaction is highly exothermic and once started generates sufficient heat to be self sustaining. In order to promote the oxidation

reaction it is necessary to preheat the feed fuel and to reduce temperature variations in the reactor.

Patent application US 6,770,106, for example describes a partial oxidizing reformer for reforming feed gas containing hydrocarbon or methane wherein the reduction of temperature variations is achieved by an reactor being covered with a passage for preheated feed gas and therefore being thermally isolated by the feed gas passage. The reaction heat is recovered by a heat exchanger for the purpose of preheating the feed gas.

10

Auto-thermal reforming processes are a combination of steam reforming and partial oxidation reforming. Waste heat from the partial oxidation reforming reaction is used to heat the endothermic steam reforming reaction.

The natural by-products of all reforming processes are carbon monoxide and carbon dioxides. But, since the hydrocarbon fuels were not designed as a feed stock for generating hydrogen, there are also other by-products such as sulphur, olefins, benzene, methyl amid and higher molecular weight aromatics. These by-products may be harmful to the fuel cells and should therefore be removed by subsequent steps outside the reformer reactor.

20

Another disadvantage is that hydrocarbon fuels, especially diesel, tend to burn to soot by contact with the inside surfaces of the reactor. Soot particles again, are very harmful to the fuel cells and have to be removed before the reformed hydrogen is applied to the fuel cells.

25

Therefore, it is object of this invention to reduce the risk of fuel molecules burning to soot by coming into contact with the inside surfaces of the reactor.

This object is solved by a reformer reactor according to claim 1 as well as a method according to claim 17.

30

According to the present invention the inner wall and therefore the inside surfaces of a reaction space is charged with a first electric charge. This takes into account that the fuel molecules sprayed into the reaction chamber by a fuel inlet are charged. Charging the inner walls of the reactor housing with a certain electric

5 charge statistically prevents 50% of the fuel molecules to come into contact with the inside surfaces of the reaction chamber because of electrostatic repulsion. This reduces the risk of fuel molecules burning to soot, significantly.

According to another advantageous embodiment also the fuel inlet is charged.

10 Preferably, the fuel inlet is charged with equal electric charge as the inner wall. This results in that all fuel molecules have the same electric charge as the inner wall and are therefore electrically repelled there from. Thus, it is almost impossible that the fuel molecules come into contact with the inner wall and burn to soot.

15 Another preferred embodiment is provided with a catalyst for the auto-thermal reaction inside the reaction chamber to accelerate the conversion of hydrocarbon fuel into hydrogen rich gas. Preferably, the catalyst can also be charged. This is realised in another embodiment, wherein the electric charge of the catalyst is opposite to the electric charge of the inner wall and/or the fuel inlet. This accelerates the

20 fuel/oxidising agent mixture toward the catalyst and consequently accelerates the conversion reaction. The catalyst can be a ceramic monolith or metal grid.

A further preferred embodiment of the present invention takes advantage of the fact that formation of soot by burning of fuel particles in contact with the inner

25 walls of the reactor occurs only above a certain wall temperature. Remains the wall temperature below, for example by cooling the walls or by keeping the temperature of the reaction space below a certain level, the burning of fuel particles to soot is prevented.

30 Generally, there is the possibility to provide the reactor with an external cooling device but this increases the dimension of the reactor and adds a further consumer of energy to the system being supplied with energy by the fuel cells.

Therefore, the preferred embodiment uses the relatively cool oxidising agent for cooling the inner wall of the reactor. That means at the same time that a thermal isolation of the inner wall can be left out, whereby the dimension of the reactor is further reduced.

5

Another advantage of the cooling of the inner wall is that the temperature inside the reaction chamber can be held constant and the temperature of the oxidising agent can be controlled.

10 As shown in another preferred embodiment of the present invention, the oxidising agent outlet provided in the inner wall of the housing is formed as a plurality of holes. This facilitates the homogenous distribution of oxidising agent in the reaction chamber. Preferably, size, shape and/or location of the holes can vary according to the used oxidising agent, the used hydrocarbon fuel and/or their
15 temperature. Most preferably, the oxidising agent outlet is provided in the vicinity of the fuel inlet.

Other preferred embodiments and advantages are defined in the sub-claims.

20 In the following a preferred embodiment of the invention will be discussed with help of a drawing. The description is considered as exemplification of the principles of the invention and is not intended to limit the scope of the claims.

Fig. 1: shows a schematic view of a preferred embodiment of the present
25 invention.

Fig. 1 shows a reformer reactor according to a preferred embodiment of the invention.

30 The reformer reactor 1 has a housing 2 with an inner wall 4, an outer wall 6 and side walls 8a, 8b. Inner wall 4 and side walls 8a, 8b define a reaction chamber

10 in which hydrocarbon fuel and oxidising agent are brought together and an auto-thermal reaction can take place.

Inner wall 4 and outer wall 6 define a space 12 between them. The space 12
5 in turn forms a passage for oxidising agent 14 between an oxidising agent inlet 16 and an oxidising agent outlet 18. Oxidising agent outlet 18 is formed as a plurality of holes, which size, shape and location varies depending on the used oxidising agent 14, a used hydrocarbon fuel 20 and their temperature. The plurality of holes can have uniform size and shape, but it is also possible that the holes vary in size and shape
10 among each other.

Further, reformer reactor 1 has a hydrocarbon fuel inlet 22 which is located in one of the side walls 8a of housing 2. Preferably, fuel inlet 22 is formed as a fuel injector which provides a fuel spray in reaction chamber 10. A reformer gas outlet 24
15 is provided in the opposite side wall 8b of housing 2. Reformer gas 26 is a hydrogen rich gas which can be used for operating of fuel cells and is the product of the auto-thermal reaction.

Additionally, reformer reactor 1 includes a catalyst 28 for catalysing the auto-thermal reaction in reaction chamber 10. The catalyst 28 accelerates the auto-thermal reaction, but it is also possible to use a reformer reactor according to the present invention without a catalyst. The catalyst 28 is preferably a metal grid or ceramic monolith. But it is possible to use any other suitable substrate for the design of catalyst 28.
25

As shown in figure 1, two electric charge sources 30 and 34 are provided. Electric charge source 30 is connected to the inner wall 4 and the fuel inlet 22, thereby providing the walls of reaction chamber 10 and the molecules of the hydrocarbon fuel 20 with a first electric charge 32. In figure 1 the electrically charged
30 walls are schematically designated by exemplary positive charges. Electric charge source 34 is connected with catalyst 28 and provides the catalyst 28 with a second

electric charge 36 being opposite to the first electric charge 32. In figure 1, the opposite electric charges 36 are designated by exemplary negative charges.

In the following the operation of the reformer reactor is described by means of the exemplary conversion of diesel as hydrocarbon fuel into hydrogen with an air/steam-mixture as oxidising agent. The reaction for the conversion is auto-thermal.

According to the invention air and steam are mixed before the air/steam-mixture 14 is injected by oxidising agent inlet 16 into space 12 which serves as air/steam passage for transportation of the air/steam mixture 14 from oxidising agent inlet 16 to oxidising agent outlet 18 of the reactor.

On the way down to the plurality of outlet holes 18 in the inner wall 4 of housing 2 the air/steam-mixture 14 is used to cool the inner wall 4 of reaction chamber 10. By cooling the inner wall 4 of the reaction chamber 10 the risk that diesel fuel molecules in the reaction chamber 10 of the reactor are burned to soot when hitting the reaction chamber wall, is reduced.

Then, the air/steam-mixture 14 is forced through the holes 18 into the reaction chamber 10 of the reactor forming a homogenous air/steam fume in the reaction chamber 10. After introducing the air/steam-mixture into the reaction chamber 10, diesel fuel 20 is sprayed into the air/steam fume by means of fuel injector 22. Inside reaction chamber 10 a turbulent mixture of the air/steam-fume with the diesel fuel spray happens, wherein the fuel spray 20 is evaporated through contact with the air/steam fume. The vaporisation is explained below.

Since the inner walls 4 of reaction chamber 10 are charged with, for example, positive charge and the diesel fuel molecules of the diesel fuel spray are also charged with positive charges the diesel molecules are repelled from the walls of reaction chamber 10 by electrostatic repulsion. Therefore, the diesel molecules cannot come into contact with the heated walls of reaction chamber 10 and burn to soot, subsequently.

The walls of the reaction chamber 10 are heated by the homogenous oxidation taking place in the reaction chamber 10 when oxygen coming from the air/steam-mixture 14 reacts with "lighter" hydrocarbon molecules of the diesel fuel 20 having shorter chains ($C_xH_y + O_2 \rightarrow CO_2 + CO + H_2O$). The process heat produced by this process is used to vaporize the remaining hydrocarbon molecules (with longer chains) of the diesel fuel spray. After this process there is a homogeneous gas mixture of hydrocarbons and steam in the reaction chamber 10 since the portion of the remaining air is negligible.

10

This homogeneous gas mixture is then introduced into catalyst 28 where the hydrocarbons of the diesel fuel 20 are undergoing the auto-thermal reaction process. To accelerate the introduction of the homogenous gas mixture into the catalyst 28, the catalyst 28 can also be charged with a second charge which is opposite to the charge of the fuel molecules. In the embodiment shown the fuel molecules are positively charged. Therefore, the catalyst is charged with negative charge so that the molecules are attracted by the catalyst by means of electrostatic attraction. This accelerates the movement of the homogenous gas mixture in direction of the catalyst.

20

In the auto-thermal reaction process taking place inside the catalyst hydrogen (H), CO and CO₂ are produced as dominant process products. These products are processed in subsequent steps outside the reformer with the aim to separate H from all other process products.

25

Since the formation of soot by burning of diesel molecules is prevented by the application of electric charges and due to electrostatic repulsion, the impurities of the hydrogen rich gas are reduced. This facilitates the separation of pure hydrogen from the other process products.

Reference list:

- 1 Reformer reactor
- 2 housing
- 5 4 inner wall
- 6 outer wall
- 8a, b sides faces
- 10 reaction chamber
- 12 space = oxidising agent passage
- 10 14 oxidising agent
- 16 oxidising agent inlet
- 18 oxidising agent outlet
- 20 hydrocarbon fuel
- 22 hydrocarbon fuel inlet
- 15 24 hydrogen rich gas outlet
- 26 hydrogen rich gas
- 28 catalyst
- 30 first electric charge source
- 32 first electric charge
- 20 34 second electric charge source
- 36 second electric charge

Claims:

1. Reformer reactor (1) for converting hydrocarbon fuels (20) into a hydrogen rich gas (26) for fuel cells and/or exhaust treatment applications by auto-thermal reaction
5 having a housing (2) with an inner wall (4) and an outer wall (6) forming a space (12) in-between, and two side faces (8a, 8b), wherein the inner wall (4) and the two side faces (8a, 8b) form a reaction chamber (10) of the reformer reactor (1);
characterized in that
the inner wall (4) is charged with a first electric charge (32).
10
2. Reformer reactor (1) according to claim 1, wherein said reformer reactor (1) further comprises a fuel inlet (22) which is provided in one of the two side faces (8a).
15
3. Reformer reactor (1) according to claim 2, wherein said fuel inlet (22) is charged with the first electric charge (32).
20
4. Reformer reactor (1) according to claims 2 or 3, wherein said fuel inlet (22) is formed as a fuel injector.
5. Reformer reactor (1) according to any preceding claim, wherein further a catalyst (28) for the auto-thermal reaction is provided in the reaction chamber (10).
25
6. Reformer reactor (1) according to claim 5, wherein said catalyst (28) is charged with a second electric charge (36).
30
7. Reformer reactor (1) according to claim 5 or 6, wherein said catalyst (28) is a ceramic monolith or metal grid.
8. Reformer reactor (1) according to claim 1 and/or 3 and 6, wherein the first electric charge (32) is the opposite of the second electric charge (36).

9. Reformer reactor (1) according to any preceding claim, wherein said space (12) is designed as oxidizing agent passage between an oxidizing agent inlet (16) provided in the outer wall (6) and an oxidizing agent outlet (18) provided in the inner wall (4).
- 5
10. Reformer reactor (1) according to claims 2 and 9, wherein said oxidizing agent outlet (18) is located in the vicinity of the fuel inlet (22).
11. Reformer reactor (1) according to claims 9 or 10, wherein said oxidizing agent outlet (18) is designed as a plurality of holes introducing the oxidizing agent (14) into the reactor chamber (10).
- 10
12. Reformer reactor (1) according to claim 11, wherein said plurality of holes has various size and/or shape.
- 15
13. Reformer reactor (1) according to claim 11 or 12, wherein said plurality of holes is located in a variety of different locations.
14. Reformer reactor according to claim 12 or 13, wherein size and/or shape and/or location of the plurality of holes depend on the used hydrocarbon fuel and/or the used oxidizing agent.
- 20
15. Reformer reactor (1) according to any preceding claim, wherein said oxidizing agent (14) is air or steam or a mixture thereof.
- 25
16. Reformer reactor (1) according to claim 15, wherein the air/steam mixture is premixed.
17. Reformer reactor (1) according to any preceding claim, wherein said housing (2) is cylindrically shaped.
- 30

18. Method for converting hydrocarbon fuels into a hydrogen rich gas for fuel cells and/or exhaust treatment applications by auto-thermal reaction using a reformer reactor (1) according to claims 1 to 17.

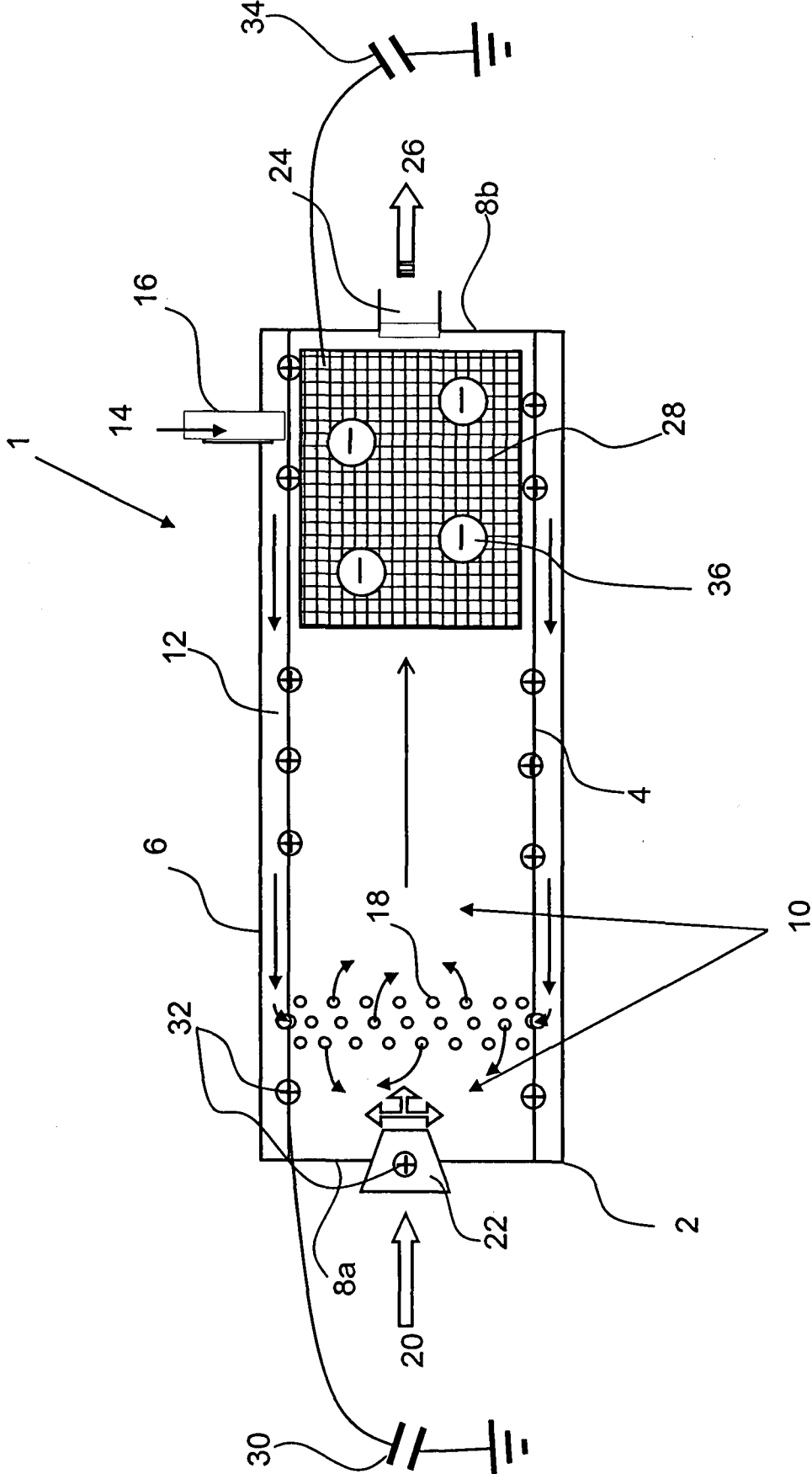


Fig. 1

INTERNATIONAL SEARCH REPORT

International application No.

PCT/SE2007/000687

A. CLASSIFICATION OF SUBJECT MATTER

IPC: see extra sheet

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC: C01B, B01J, C10G

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-INTERNAL, WPI DATA, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 20030072700 A1 (GOEBEL, STEVEN G, ET AL), 17 April 2003 (17.04.2003), paragraph [25], abstract --	1-18
A	WO 2005070818 A1 (SYNTROLEUM CORPORATION), 4 August 2005 (04.08.2005), page 12, line 14 - line 16 --	1-18
A	US 20020110507 A1 (GRIEVE, MALCOLM JAMES ET AL), 15 August 2002 (15.08.2002), figure 1, paragraph [23] --	1-18

☒ Further documents are listed in the continuation of Box C.☒ See patent family annex.

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/SE2007/000687**C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 20050086865 A1 (CRANE, JR., SAMUEL N. ET AL), 28 April 2005 (28.04.2005), claim 1 -- -----	1-18

International patent classification (IPC)**C01B 3/32** (2006.01)**B01J 19/00** (2006.01)**C01B 3/38** (2006.01)**Download your patent documents at www.prv.se**

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Use the application number as username.

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Paper copies can be ordered at a cost of 50 SEK per copy from PRV InterPat (telephone number 08-782 28 85).

Cited literature, if any, will be enclosed in paper form.

INTERNATIONAL SEARCH REPORT

Information on patent family members

26/01/2008

International application No.

PCT/SE2007/000687

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