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PRODUCTION OF HYDROGEN-CONTAINING GAS STREAMS

This application claims the priority of United States Provisional Application 60/107,127, filed November 5, 1998.

15 This invention relates to the production of a hydrogen-containing gas by catalytic reforming of a hydrocarbon feedstock.

In the catalytic reforming of a hydrocarbon feedstock to produce a hydrogen-containing gas, in general, such reforming is accomplished by the use of a reforming gas such as steam and/or carbon dioxide; in particular, steam, in the
20 presence of a suitable reforming catalyst. In general, such a feedstock comprises methane and the hydrogen-containing gas contains hydrogen and carbon monoxide, with such gas often being referred to in the art as a "synthesis gas."

The steam-reforming reaction is endothermic and is operated at high temperature in order that the equilibrium favors production of hydrogen. The heat
25 required for the endothermic reforming reaction is supplied by preheating the feed and by heating during the reforming process; in particular, the reforming reaction is accomplished in a reactor often referred to in the art as a steam reformer. Generally the steam reforming reactor is a tubular reactor where the tubes are heated in a fired furnace. However, other reactor configurations are also possible,
30 e.g. non-fired tubular reactors or pre heated adiabatic packed beds.

The present invention is directed to improving the steam-reforming process for conversion of a hydrocarbon feedstock to a synthesis gas.

In accordance with an aspect of the present invention, a synthesis gas (a gas that contains hydrogen, and also generally contains carbon monoxide), is produced by reacting steam and a hydrocarbon, with the hydrocarbon preferably being methane, in the presence of a steam-reforming catalyst, wherein the steam-reforming catalyst is supported on a mesh or mesh-like material, or the catalyst is in the form of a mesh i.e., the mesh is formed from a catalytic material.

The term "supported on the mesh" includes coating the catalyst on the mesh as well as entrapping the catalyst in the interstices of the mesh. The catalyst that is supported on the mesh, in a preferred embodiment, is comprised of a steam-reforming catalyst supported on a particulate support with the supported steam-reforming catalyst being supported on the mesh.

More particularly, the mesh like material is comprised of fibers or wires, such as a wire or fiber mesh, a metal felt or gauze, metal fiber filter or the like. The mesh like structure may be comprised of a single layer, e.g. a knitted wire structure or a woven wire structure, or may include more than one layer of wires; and is preferably comprised of a plurality of layers of wires or fibers to form a three dimensional network of materials. In a preferred embodiment, the support structure is comprised of a plurality of layers of fibers that are randomly oriented in the layers. One or more metals may be used in producing a metal mesh. Alternatively the mesh fibers may be formed from or include materials other than metals alone or in combination with metals; e.g. carbon or metal oxides or a ceramic. In a preferred embodiment, the mesh includes a metal. In the case where the mesh supports the catalyst the material forming the mesh is preferably non-catalytic with respect to steam reforming. As hereinabove indicated, in one embodiment, the material forming the mesh is a steam-reforming catalyst.

In a preferred embodiment wherein the mesh like structure is comprised of a plurality of layers of fibers to form the three dimensional network of materials the thickness of such support is at least five microns, and generally does not exceed ten millimeters. In accordance with a preferred embodiment, the thickness

of the network is at least 50 microns and more preferably at least 100 microns and generally does not exceed 2 millimeters.

In general, the thickness or diameter of the fibers which form the plurality of layers of fibers is less than about 500 microns, preferably less than about 150
5 microns and more preferably less than about 30 microns. In a preferred embodiment the thickness or diameter of the fibers is from about 8 to about 25 microns.

The three dimensional mesh like structure may be produced as described in U.S. Patent Number 5,304,330; 5,080,962; 5,102,745 or 5, 096,663. It is to be
10 understood, however, that such mesh like structure may be formed by procedures other than as described in the aforementioned patents.

In the preferred embodiment where the mesh-like structure supports a steam-reforming catalyst on a particulate support, the particulate catalyst support is a porous support and in a preferred embodiment, has a surface area that is
15 greater than $1\text{m}^2/\text{g}$, and preferably a surface area greater than $5\text{m}^2/\text{g}$. In most cases, the surface area does not exceed $100\text{m}^2/\text{g}$. The surface area is measured by the Brunauer Emmett and Teller (BET) method. The support is a porous support that is heat resistant, and as representative examples of such supports there may be mentioned alumina, silicon carbide, silica, zirconia, titania, calcium aluminate,
20 calcium aluminum titanate, a silica/alumina support etc.

The catalyst support on which the steam-reforming catalyst is supported is a support that is in particulate form (with such supported catalyst being supported on the mesh-like structure). The term particulate as used herein includes and encompasses spherical particles, elongated particles, fibers, etc. In general, the
25 particulate support has an average particle size of at least 0.5 micron and no greater than 20 microns although larger particles may be employed. In some cases, the particle size may be as low as 0.002 micron. In the case where the support particles are entrapped, the particulates are no greater than 300 μm . preferably no greater than 200 μm and most preferably no greater than 100 μm .
30 When coating the catalyst on the mesh, the particulate support in the majority of cases does not exceed 10 microns.

The steam catalyst reforming may be of a type known in the art. In general, such catalyst includes nickel, ruthenium or rhodium, with or without promoters such as alkali metals.

5 In accordance with an aspect of the present invention, the steam-reforming catalyst (with or without a support) is supported on the mesh like structure in an amount of at least 5%, and preferably at least 10%, with the amount of catalyst generally not exceeding 60% and more generally not exceeding 50%, all by weight, based on mesh, catalyst, and, if present, particulate support.

10 In an embodiment of the invention, the mesh like structure that is formed from a steam reforming catalyst and/or functions as a support for the steam-reforming catalyst (the mesh-like structure preferably supports a steam-reforming catalyst supported on a particulate support) is in the form of a shaped structured packing to provide for turbulence of the gas phase flowing over the catalyst in the steam-reforming tubes. The mesh structure may be provided with suitable
15 corrugations in order to provide for increased turbulence. Alternatively, the mesh like structure may include tabs or vortex generators to provide for turbulence. The presence of turbulence generators permits mixing in the radial (and longitudinal) direction and permits improved heat transfer at the wall compared to the processes know in the art. This can be effected by adding turbulence generators to the
20 structure that contacts the wall. For example, the structural packing can be in the form of a module such as a roll of one or more sheets that is placed into the tubes of the reactor such that the channels in the module follow the longitudinal direction of the tube. The roll can consist of sheets that are flat, corrugated or wavy or a combination thereof and the sheets can contain fins or holes to promote
25 mixing. The sheets can also be shaped into corrugated strips that are separated from each other by a flat sheet that exactly fit the size of the tube and are held together by welds, wires, a cylindrical flat sheet or combinations thereof.

It is to be understood that the mesh that is formed from a steam reforming catalyst or that supports the steam-reforming catalyst (which steam-reforming
30 catalyst may or may not be supported on a particulate support) may be employed in a form other than as a structured sheet. For example, the mesh may be formed

as rings, particles, ribbons, etc. and employed in the tubes as a packed bed. In one embodiment the particle dimensions are smaller than those of packed bed particles that are known in the prior art. Thus, the supported catalyst on the mesh (whether or not used as a structured packing is preferably employed as a packed bed.

5 The steam-reforming catalyst which is supported on the mesh like structure may be present on the mesh like support as a coating on the wires or fibers that form the mesh like structure and/or may be present and retained in the interstices of the mesh like structure.

10 In one embodiment, wherein the steam-reforming catalyst supported on a particulate support is present as a coating on the mesh, the mesh may be initially coated with the particulate support, followed by addition of the steam-reforming catalyst to the particulate support present as a coating on the mesh. Alternatively, the catalyst supported on a particulate support may be coated onto the mesh. The particulate support with or without catalyst may be coated on the mesh by a
15 variety of techniques, e.g., dipping or spraying.

20 The supported catalyst particles may be applied to the mesh-like structure by contacting the mesh-like structure with a liquid coating composition (preferably in the form of a coating bath) that includes the particles dispersed in a liquid under conditions such that the coating composition enters or wicks into the mesh-like structure and forms a porous coating on both the interior and exterior
portions of the mesh-like structure.

Alternatively, the mesh-like structure is coated with a particulate support containing active catalyst or the mesh-like structure may be coated with particles of a catalyst precursor.

25 In a preferred embodiment, the liquid coating composition has a kinematic viscosity of no greater than 175 centistokes and a surface tension of no greater than 300 dynes/cm.

30 In one embodiment, the supported catalyst or catalyst support is coated onto the mesh by dip-coating. In a preferred embodiment, the three-dimensional mesh-like material is oxidized before coating; e.g., heating in air at a temperature of from 300°C up to 700°C. In some cases, if the mesh-like material is contaminated with

organic material, the mesh-like material is cleaned prior to oxidation; for example, by washing with an organic solvent such as acetone.

The coating bath is preferably a mixed solvent system of organic solvents and water in which the particles are dispersed. The polarity of the solvent system is preferably lower than that of water in order to prevent high solubility of the catalyst and to obtain a good quality slurry for coating. The solvent system may be a mixture of water, amides, esters, and alcohols. The kinematic viscosity of the coating bath is preferably less than 175 centistokes and the surface tension thereof is preferably less than 300 dynes/cm.

In a preferred embodiment of the invention, the mesh-like structure that is coated includes metal wires or fibers and the metal wires or fibers that are coated are selected or treated in a manner such that the surface tension thereof is higher than 50 dynes/cm, as determined by the method described in "Advances in Chemistry, 43, Contact Angle, Wettability and Adhesion, American Chemical Society, 1964."

In coating a mesh-like structure that includes metal fibers, the liquid coating composition preferably has a surface tension from about 50 to 300 dynes/cm, and more preferably from about 50 to 150 dynes/cm, as measured by the capillary tube method, as described in T.C. Patton, "Paint Flow and Pigment Dispersion", 2nd Ed., Wiley-Interscience, 1979, p. 223. At the same time, the liquid coating composition has a kinematic viscosity of no greater than 175 centistokes, as measured by a capillary viscometer and described in P.C. Hiemenz, "Principles of colloid and Surface Chemistry", 2nd Ed., Marcel Dekker Inc., 1986, p. 182.

In such an embodiment, the surface tension of the metal being coated is coordinated with the viscosity and surface tension of the liquid coating composition such that the liquid coating composition is drawn into the interior of the structure to produce a particulate coating on the mesh-like structure. The metal to be coated preferably has a surface tension which is greater than 50 dynes/cm and preferably is higher than the surface tension of the liquid coating composition to obtain spontaneous wetting and penetration of the liquid into the interior of the mesh.

In the case where the metal of the structure that is to be coated does not have the desired surface tension, the structure may be heat-treated to produce the desired surface tension.

The liquid coating composition can be prepared without any binders or adhesives for causing adherence of the particulate coating to the structure.

The surface of the structure to be coated may also be chemically or physically modified to increase the attraction between the surface and the particles that form the coating; e.g., heat treatment or chemical modification of the surface.

The solids content of the coating bath generally is from about 2 % to about 50%, preferably from about 5% to about 30%.

The bath may also contain additives such as surfactants, dispersants etc. In general, the weight ratio of additives to particles in the coating bath is from 0.0001 to 0.4 and more preferably from 0.001 to 0.1.

The mesh-like material preferably is coated by dipping the mesh-like material into a coating bath one or more times while drying or calcining in between dippings. The temperature of the bath is preferably at room temperature, but has to be sufficiently below the boiling point of the liquid in the bath.

After coating, the mesh-like material that includes a porous coating comprised of a plurality of particles is dried, preferably with the material in a vertical position. The drying is preferably accomplished by contact with a flowing gas (such as air) at a temperature of from 20°C to 150°C more preferably from 100°C to 150°C. After drying, the coated mesh-like material is preferably calcined, for example, at a temperature of from 250°C to 800°C, preferably 300°C to 500°C, most preferably at about 400°C. In a preferred embodiment, the temperature and air flow are coordinated in order to produce a drying rate that does not affect adversely the catalyst coating, e.g., cracking, blocking of pores, etc. In many cases, a slower rate of drying is preferred.

The thickness of the formed coating may vary. In general, the thickness is at least 1 micron and in general no greater than 100 microns. Typically, the coating thickness does not exceed 50 microns and more typically does not exceed 30 microns.

The interior portion of the mesh material that is coated has a porosity which is sufficient to allow the particles which comprise the coating to penetrate or migrate into the three dimensional network. Thus, the pore size of the three dimensional material and the particle size of the particles comprising the coating, in effect, determine the amount and uniformity of the coating that can be deposited in the interior of the network of material and/or the coating thickness in the network. The larger the pore sizes the greater the thickness of the coating which can be uniformly coated in accordance with the invention.

In the case where the particles are in the form of a catalyst precursor, the product, after the deposit of the particles, is treated to convert the catalyst precursor to an active catalyst. In the case where the particles which are deposited in the three dimensional network of material is a catalyst support, active catalyst or catalyst precursor may then be applied to such support, e.g., by spraying, dipping, or impregnation.

In using a coating bath, the coating bath in some cases may include additives. These additives change the physical characteristics of the coating bath, in particular the viscosity and surface tension such that during dipping penetration of the mesh takes place and a coating can be obtained with a homogeneous distribution on the interior and exterior of the mesh. Solvents not only change the physical properties of the coating bath, but also act as binders. After the deposition, the article is dried and calcined.

As representative stabilizing agents there may be mentioned: a polymer like polyacrylic acid, acrylamines, organic quaternary ammonium compounds, or other special mixes which are selected based on the particles. Alternatively an organic solvent can be used for the same purpose. Examples of such solvents are alcohols or liquid paraffins. Control of the pH of the slurry, for example, by addition of HNO_3 is another method of changing the viscosity and surface tension of the coating slurry.

In a preferred embodiment wherein the mesh is comprised of a plurality of layers of metal fibers, the particulate support with or without catalyst may be coated onto the mesh by an electrophoretic coating procedure, as described in U.S. Application Serial Number 09/156,023, filed on September 17, 1998. In such a

procedure, the wire mesh is employed as one of the electrodes, and the particulate support, such as an alumina support of the requisite particle size, with or without catalyst, (which preferably also includes alumina in the form of a sol to promote the adherence of larger particles to the wire mesh) is suspended in a coating bath.

- 5 A potential is applied across the electrodes, one of which is the mesh formed from a plurality of layers of fibers, and the mesh is electrophoretically coated with the alumina support with or without catalyst. If the alumina support does not include a catalyst, the steam-reforming catalyst, which is preferably comprised of nickel particles with or without one or more promoters, is then added to the catalyst
10 structure by dipping the structure (which contains the alumina coating) into or impregnating the structure with an appropriate solution that contains the nickel catalyst and preferably one or more promoters. The Example illustrates preparation of a catalyst by electrophoretic coating.

- As hereinabove indicated, the steam-reforming catalyst (with or without a
15 particulate support) may be supported on the mesh material by entrapping or retaining the catalyst in the interstices of the mesh. For example, in producing a mesh comprised of a plurality of layers of randomly oriented fibers, a particulate support may be included in the mix that is used for producing the mesh whereby the mesh is produced with the particulate support retained in the interstices of the
20 mesh. For example, such mesh may be produced as described in the aforementioned patents, and with an appropriate alumina support being added to the mesh that contains the fibers and a binder, such as cellulose. The thus produced mesh includes the alumina particles retained in the mesh. The particulate support retained in the mesh is then impregnated with nickel by
25 procedures known in the art.

- The term "bed void volume" as used herein means the open space in the portion of the reaction zone (for example the tubes of a steam reforming catalyst) that is not occupied by the mesh wherein the openings or pores in the mesh and the openings or pores in any catalyst or particulate support on the mesh is
30 considered as being occupied by the mesh. Thus, in determining "bed void

volume" the mesh is considered to be a closed sheet and any catalyst and particulate support on the mesh is considered to be free of pores.

The term "mesh catalyst void volume" means the total of open space in the mesh and the open space in any particulate support and catalyst on the mesh.

5 The "bed void volume percent" is the ratio of the bed void volume to the total volume of the portion of the reaction zone in which the mesh is placed multiplied by 100.

10 The "mesh catalyst void volume percent" is the ratio of open volume in the mesh, particulate support and catalyst divided by the total volume of mesh, particulate support and catalyst (including pores or openings) multiplied by 100.

The "mesh void volume percent" is the ratio of void volume in the mesh without catalyst or particulate support to the total volume of the mesh structure (openings and mesh material) multiplied by 100.

15 The mesh like structure that is employed in the present invention (without catalyst and/or particulate support on the mesh) has a mesh void volume percent that is at least 45%, and is preferably at least 55% and is more preferably at least 65% and still more preferably is at least about 85% or 90%. In general, the mesh void volume percent does not exceed about 98%. In general, the average void opening is at least 10 microns and preferably at least 20 microns.

20 The steam-reforming reaction is generally effected in a tubular furnace, often referred to as a steam-reformer or a steam-reforming furnace, which furnace includes a plurality of tubes that are appropriately heated in the furnace. In accordance with a preferred aspect of the present invention, the mesh catalyst (in the form of a wire mesh that is the steam-reforming catalyst or in the form of a
25 mesh that supports the steam-reforming catalyst with or without a particulate support) is employed in the reaction zone (for example, the tubes in the furnace) in an amount such that the bed void volume percent is at least 70%. In most cases the bed void volume percent is no greater than 97%. For example, in the case where the steam-reforming catalyst (with or without a particulate support)
30 supported on the mesh is in the form of a packed bed, the bed void volume percent is generally between 70% and 97%. In the case where the steam-

reforming catalyst, with or without a particulate support, is supported on a mesh in the form of a structured packing, as opposed to a packed bed, the bed is generally from 70% to 97% void volume percent and. In general the mesh catalyst void volume percent is at least 50% preferably at least 60% and generally does not exceed 90%. In the case where the steam-reforming catalyst is supported on a particulate support, the catalyst is generally present on the particulate support in an amount from 3 to 20%, by weight, based on catalyst and particulate support.

The steam reforming is generally accomplished at outlet temperatures of at least 700°C, with the outlet temperature in most cases not exceeding 900°C. The inlet temperature to the steam-reforming is generally in the order of at least 500°C, and generally does not exceed 600°C. The outlet pressure of the tubes that contain the steam-reforming catalyst is generally in the order of from about 15 to 60 bar with the pressure drop through the tubes generally not exceeding 0.42 bar/meter of tube length, and preferably not exceeding 0.31 bar/m. The steam-reforming feed is generally comprised of a hydrocarbon (preferably methane) and steam, with the steam-to-hydrocarbon ratios generally being at least 1.5, and generally not exceeding 6:1.

The steam-reforming reaction may be accomplished in any one of a wide variety of steam-reforming furnaces, and may be combined with other processes; for example, a shift reaction to increase the content of hydrogen and to reduce the carbon monoxide content.

In a separate embodiment, steam reforming is effected in multiple stages where the heat is generated in one of the stages is used to provide or supplement the heat required for other stages. This can be done either in tubular reactors heated by hot gases or by using hot gases to preheat the feed to an adiabatic reactor.

The present invention will be further described with respect to the following examples; however, it is to be understood that the scope of the invention is not to be limited thereby:

EXAMPLE 1

Small-scale preparation of a Ni containing steam reforming catalyst on a wire mesh.

- 5 The support of 5 x 5 cm is a metal mesh with a thickness of 0.8mm. stainless steel fibers of 12 μm in diameter and a mesh void volume percent of 90%. the metal mesh is composed of a plurality of layers of metal fibers. The mesh is placed vertically in a bath containing a slurry. The aqueous slurry contains 10 wt% alumina catalyst support with a surface area of about 10 m^2/g ,
10 0.11 wt% Nyacol™ 20% alumina sol and 0.055 wt% of a commercial quaternary ammonium chloride agent. The pH of the slurry was adjusted with diluted HNO_3 to 5.5. The mesh is connected to the negative pole of a power supply and is placed between and parallel to two vertical metal electrodes, which are connected to the positive pole of a power supply. A potential of 5 V is applied for 2 minutes,
15 during which the alumina is deposited into the mesh. The sample is calcined in air at 500°C for 60 minutes. The amount of catalyst support that is deposited on the mesh is 25.1% by weight of the combined mesh support and catalyst. The coated wire mesh is impregnated to the incipient wetness point with 1.10 g of a 20 wt% $\text{Ni}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$ containing aqueous solution. The impregnated sample is heated in
20 air at 525°C for 60 minutes to convert the $\text{Ni}(\text{NO}_3)_2$ to NiO. After calcination the alumina on the support contains about 15 wt% of NiO.

EXAMPLE 2

- Twenty weight percent of Nickel oxide on calcium aluminate in distilled
25 water slurry was further milled in an Eiger Mill to obtain a slurry with a mean

particle size of < 3 microns. One tenth of one percent of Stockhausen, a dispersent, and 0.1 wt percent of 20 % alumina sol (Nyacol™) in water were added and mixed well with a magnetic stirrer. This slurry was further diluted with distilled water to 10 wt percent for dip coating.

- 5 Three monolith structure packings (1" dia. x 1" length) made with Inconel 600 fiber mesh material from US Filter Inc. were washed with acetone and heat-treated at 350° C for one hour. Each structure was dipped into the prepared slurry, followed by removing excess slurry by an air gun, air-drying for 15 min. and oven-drying at 125° C for one hour. This operation was repeated four more times.
- 10 The average weight gains after each dipping were 6.1, 11.4, 16.1, 21.1, and 24.7 wt %, respectively. These coated monolith were finally subjected to calcining at 500° C for one hour prior to testing for syngas reaction. The average loading of catalyst was 21.6 wt %.

EXAMPLE 3

- 15 The same procedures for slurry and monolith preparation as Example 1 and 2 were used. Dip-coating procedures were also the same except that two additional successive coatings were carried out for three monolith structures to achieved higher catalyst loading. The weight gains after each dipping were 6.5,
- 20 12.2, 17.4, 22.3, 25.7, 29.1, and 31.8 wt %, respectively. The catalyst loading was determined to be 28.2 wt % after calcining at 500° C for one hour.

The present invention is particularly advantageous in that mass transfer limitations in the catalyst are reduced by applying a thin coating of catalyst on the surface of a highly porous fibrous metal mesh. Consequently a volumetric

activity can be obtained that is higher than or similar to processes of the prior art with a reduced amount of steam reforming catalyst. As a result of the high void volume of the catalyst bed and of the mesh catalyst it is possible to effect the steam reforming at a lower pressure drop than in processes of the prior art.

5 In addition, the present invention permits the reaction to be effected with an improved heat transfer at the wall, e.g. by employing the mesh as a structured packing, preferably with turbulence generators that contact the wall, or as a packed bed with smaller dimensions compared to those applied in processes known in the art. At a particular heat flux the improved heat transfer per pressure
10 drop and improved mass transfer allow the steam reforming process to be operated at a lower wall temperature which extends tube life. The lower temperature reduces coke formation on the catalyst and consequently allows the use of lower steam/carbon ratios (typically lower than 3) than in processes of the prior art. This results in a reduction of the separation costs downstream. The higher
15 volumetric activity and improved heat transfer also allow a higher heat flux through the wall, which is particularly useful if a high methane conversion is required.

Numerous modifications and variations of the present invention are possible in light of the above techniques; therefore, within the scope of the
20 appended claims, the invention may be practiced otherwise than as particularly described.

WHAT IS CLAIMED IS

1. A process for producing a synthesis gas, comprising: reacting a hydrocarbon and steam in a steam reforming reaction zone in the presence of a mesh
5 selected from the group consisting of a mesh formed of a steam-reforming catalyst and a mesh supporting a steam-reforming catalyst.
2. The process of Claim 1 wherein the mesh is a steam-reforming catalyst and the reaction zone has a bed void volume percent of at least 75% and no greater than 97%.
- 10 3. The process of Claim 1 wherein the mesh is a mesh supporting a steam-reforming catalyst and the steam reforming zone has a bed void volume percent of at least 70% and the mesh catalyst void volume percent is at least 50%.
- 15 4. The process of Claim 3 wherein the steam-reforming catalyst is supported on a particulate support, and the particulate support is supported on the mesh.
5. The process of claim 4 wherein the catalyst and particulate support are present on the mesh in an amount of at least 5% by weight.
6. The process of Claim 4 wherein the catalyst comprises at least one of nickel, rhodium, or ruthenium.
- 20 7. The process of Claim 6 wherein the mesh comprises a plurality of layers of metal fibers.
8. The process of Claim 7 wherein the supported catalyst is coated on the mesh.
9. The process of Claim 7 wherein the supported catalyst is entrapped in the interstices of the mesh.
- 25 10. The process of Claim 4 wherein the combination of steam-reforming catalyst and particulate support is present in an amount of at least 5% and no greater than 60% by weight based on catalyst, particulate support and mesh.
11. The process of claim 10 wherein the pressure drop through the portion of the reaction zone that contain the catalyst is no greater than 0.42 bar/m.



12. The process of Claim 10 wherein the catalyst is present on the particulate support in an amount of from 3% to 20%, by weight, based on weight of catalyst and particulate support.
13. The process of Claim 1 wherein the steam reforming catalyst is supported on a particulate support supported on the mesh.
14. The process of Claim 13 wherein the mesh is in the form of a structured packing.
15. The process of Claim 13 wherein the average particle size of the support is less than 200 microns.
- 10 16. The process of Claim 15 wherein the average particle size of the support is no greater than 20 microns.
17. The process of Claim 15 wherein the mesh has a thickness of at least 5 microns and no greater than 2mm and is comprised of a plurality of layers of metal fibers.
- 15 18. The process of Claim 17 wherein the reaction zone has a bed void volume percent of at least 60% and no greater than 97%.
19. The process of Claim 18 wherein the reaction zone is a tubular reaction zone.
20. A catalyst comprising: a steam-reforming catalyst supported on a mesh, said mesh comprising a plurality of layers of metal fibers, said metal fibers having a thickness of less than 30 microns.
- 20 21. The catalyst of Claim 20 wherein the steam reforming catalyst comprises active catalyst on a particulate support and the support is coated on the mesh.
22. The catalyst of Claim 20 wherein the particulate support has an average particle size of no greater than 20 microns.