

MANUFACTURING PROCESS OF CATALYST COATED MEMBRANE (CCM) FOR FUEL CELL APPLICATIONS

Technical Field

- 5 [0001] The present disclosure relates to an apparatus for manufacturing a catalyst coated membrane. The present disclosure relates to a method for manufacturing the catalyst coated membrane, wherein the method involves use of the apparatus.

Background

- 10 [0002] Catalyst coated membrane (CCM) is one of the critical stack components (see FIG. 1) in a fuel cell and fuel cell stack, which facilitates electrochemical conversion of fuel to electrical energy. A catalyst coated membrane may include a proton exchange membrane in electrical contact with each of the electrodes (e.g. an anode and a cathode), which utilize a precious metal catalyst and permit diffusion of the reactants to the electrodes. One of the impeding factors for fuel cell commercialisation is high cost, with the catalyst coated membrane constituting 30% to 50% of the total fuel cell cost and reducing platinum loading is an important research area for fuel cell development.

- 15 [0003] Many commercial companies may have paid great attention to the manufacturing process of the catalyst coated membrane. FIG. 2 shows a comparison of the two different methods for traditional fabrication of catalyst coated membrane. Currently, catalyst coated membranes tend to be fabricated via two approaches, either (a) transfer of electrocatalyst layers (referred to as decal transfer in FIG. 2) via a flexible substrate to the membrane surface or (b) multiple direct spray deposition process where the multiple catalyst layers may be directly sprayed on a membrane surface (and multiple dispensers or a dispenser having multiple nozzles tend to be required).

- 20 [0004] In the first approach (a), the transfer of electrocatalyst layers via a flexible substrate to the membrane surface may involve multiple steps. One reported example describes a process for forming a catalyst coated membrane via a roll-to-roll manufacturing method whereby the electrocatalyst layers were transferred via a flexible substrate to the membrane surface. However, this involved many undesirable complex steps and the tedious process of coating the electrocatalyst on the substrate first before transferring it to the membrane, which involves high cost. Another reported example described a method for forming a catalyst layer directly on a proton conductive membrane by a decal process whereby a catalytic layer composition was coated on a support and then peeled off to obtain a thin catalyst film. The catalyst film was pressed into the surface of a proton exchange membrane to form a resultant catalytic layer. However, the disadvantages of using the decal transfer method include poor dispersion of catalyst particles and catalyst degradation during this hot pressing process. Defects such as cracking may occur during the transfer and peeling step, and not 100% of the electrocatalyst may be transferred onto the membrane.

- 30 [0005] In the second approach (b), the direct spray deposition process may be deemed to have simplified the steps (as compared to the first approach) by involving the coating of catalyst layers directly on the membrane surface. Certain reported examples adopt a direct spray deposition process where the catalyst layers were directly applied to the membrane. The process required multiple stacked catalyst layers to be formed directly on the membrane through alternating spraying and vaporizing steps. The multiple layers were formed from multiple inks comprising catalyst particles having different average particle sizes. However, the multiple inks required tend to result in higher wastage of catalyst,
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agglomeration of catalyst, and nozzle blockage during the spray process. Using the multiple layer approach was time-consuming and faces issues such as defects between the layers.

[0006] There may have been a few other reported examples that may have addressed some but not all of the issues mentioned above. Despite this, certain processing steps associated with a catalyst coated membrane manufacturing process, particularly those steps that considerably affect fuel cell performance, may have been kept as trade secrets rather than being made known, albeit perhaps not addressing all of the issue mentioned above. In other words, there appears to be insufficient development for improving a catalyst coated membrane, especially for fuel cell applications.

[0007] There is thus a need to provide for a solution that addresses one or more of the limitations mentioned above. The solution should at least provide for a method and an apparatus for manufacturing a catalyst coated membrane, especially for fuel cell applications.

Summary

[0008] In a first aspect, there is provided an apparatus for manufacturing a catalyst coated membrane, the apparatus comprising:

a first element configured to receive a membrane;

a second element co-operable with the first element to secure the membrane to the apparatus,

wherein the first element and the second element are detachable from each other when not in use, and when in use are configurable to be arranged in a manner which

(i) secures the membrane to the first element and the second element, and

(ii) for vacuum suction to be applied to the membrane.

[0009] In another aspect, there is provided a method for manufacturing a catalyst coated membrane, the method comprising:

providing a membrane;

securing a membrane to the apparatus described in various non-limiting embodiments of the first aspect; and

depositing a catalyst ink containing catalyst particles onto the membrane.

Brief Description of the Drawings

[0010] The drawings are not necessarily to scale, emphasis instead generally being placed upon illustrating the principles of the present disclosure. In the following description, various embodiments of the present disclosure are described with reference to the following drawings, in which:

[0011] FIG. 1 shows a general overview of a catalyst coated membrane in a traditional fuel cell.

[0012] FIG. 2 is a table comparing two different traditional approaches for fabricating a catalyst coated membrane and some of the steps that may be involved in each approach.

[0013] FIG. 3A shows certain non-limiting embodiments of the present apparatus. Specifically, FIG. 3A shows the apparatus includes a polymeric (e.g. acrylic) jig holder (as a first element) configured to secure any membrane thereto. This jig holder, in such embodiments, may be referred herein to as a first element. The first element is referred to as a "jig" holder as it is configured to control and/or confine the location and/or motion of another item or a part of the item. As can be seen in FIG. 3A, the first element

has an area demarcated for which the second element and/or membrane can be placed within the first element. The area may be positioned in the center of the first element. The area may be configured (e.g. dimensioned) to have a membrane arranged therein. The area is also configured to have a second element of the apparatus arranged therein.

5 The demarcation helps in aligning the arrangement of a membrane and the second element therein. The second element of the apparatus is shown in FIG. 3B. The thickness of the first element may be dimensioned to have the second element and the membrane housed therein. For example, the second element and the membrane are stacked therein and flushed with the top and bottom surfaces of the first element (see

10 top image in FIG. 4B).

[0014] FIG. 3B shows certain non-limiting embodiments of the present apparatus. Specifically, FIG. 3B shows the apparatus includes another detachable “jig” (e.g. acrylic) which has holes. In such embodiments, this detachable “jig” may be referred herein to as the second element. As mentioned above and in the examples further

15 hereinbelow, the second element and the first element can be arranged together so as to be co-operable to secure a membrane to the apparatus. The second element can be arranged in the first element. For example, the second element may be housed within the demarcated area of the first element (also see FIG. 4B). The holes of the second element may be of same or different diameter. The holes can be of any size or shape as

20 long as suction vacuum can be applied through the holes so as to secure a membrane to the second element and the first element. The suction vacuum helps confine the location and movement of the membrane arranged on the second element and within the first element. In certain instances, the second element may be arranged on the membrane. In certain instances, the membrane may be arranged on the second element. The

25 arrangement of the second element and the membrane depends on the side of the membrane to be coated with the catalyst ink.

[0015] FIG. 3C shows a top view (top image) and a side cross-sectional view (bottom image) of a membrane having protective layers on both sides of the membrane. The protective layers are removable from the membrane.

[0016] FIG. 4A is a schematic diagram (not drawn to scale) showing a method of the present disclosure carried out with an apparatus of certain non-limiting embodiments of the present disclosure. FIG. 4A shows the step-by-step process for spray coating of a membrane using the apparatus shown in FIG. 3A to 3C. As can be seen in step 402, there is a gap between the membrane and the first element. The gap allows for the ease

30 of removal of the protective layer. In step 404, a tape may be applied as shown to help secure the membrane to the first element. The apparatus of the present disclosure may be configured to cater to the size of the membrane. In this non-limiting instance, the apparatus houses a membrane of 30 to 40 cm by 30 to 40 cm (e.g. 35 cm by 35 cm).

[0017] FIG. 4B shows the cross-section views for arrangement of the first element, the second element, and/or the membrane, in various steps of FIG. 4A. For instance, in the top image for step 402, it is shown that the second element 4002 (with holes 4004) is arranged in the first element 4000. The first element 4000, the membrane 4006, and the second element 4002 may be placed on a platform of a spray chamber (not shown) for spraying a catalyst ink on the membrane, such that the holes 4004 are to be aligned to

35 the holes of the platform. Vacuum suction may be applied to the membrane and the holes 4004 to allow the vacuum to hold the membrane in place (in addition to any tapes), which also helps prevent membrane swelling during the spraying of catalyst ink. The membrane 4006 (having pores 4008) with a protective layer 4010 is arranged in the first

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element 4000 and on the second element 4002. The protective layer 4010 faces the second element 4002. In the second image from top for step 406, it is shown that a catalyst ink 4012 is coated (e.g. spray coated) on the membrane 4006. In the third image from top for step 408, it is shown that the first element 4000 (housing the membrane 4006 and the second element 4002) is flipped over to expose the other surface of the membrane 4006 that has not been coated with the catalyst ink 4012. Prior to flipping, a protective layer (not shown) may be taped to the first element 4000 to cover the surface of the membrane 4006 that was coated with the catalyst ink. In the bottom-most image for step 410, it can be seen that the second element 4002 is removed from the first element 4000 and the membrane 4006.

[0018] FIG. 5 shows another apparatus of the present disclosure.

[0019] FIG. 6 is a schematic diagram showing a method of the present disclosure carried out with an apparatus of certain non-limiting embodiments of the present disclosure. FIG. 6 shows the step-by-step process for spray coating of a membrane using the apparatus shown in FIG. 5.

Detailed Description

[0020] The following detailed description refers to the accompanying drawings that show, by way of illustration, specific details and embodiments in which the present disclosure may be practised.

[0021] Features that are described in the context of an embodiment may correspondingly be applicable to the same or similar features in the other embodiments. Features that are described in the context of an embodiment may correspondingly be applicable to the other embodiments, even if not explicitly described in these other embodiments. Furthermore, additions and/or combinations and/or alternatives as described for a feature in the context of an embodiment may correspondingly be applicable to the same or similar feature in the other embodiments.

[0022] The present disclosure relates to an apparatus for manufacturing a catalyst coated membrane. The present disclosure also relates to a method for manufacturing a catalyst coated membrane carried out using the apparatus.

[0023] The present apparatus and method are advantageous for addressing or circumventing one or more of the limitations mentioned above.

[0024] In addition, the present apparatus and method are able to address the challenges from direct spray coating, e.g. spraying directly a catalyst ink onto a membrane to coat the membrane with catalyst particles. The present apparatus and method are compatible with the usage of spray coating (even direct spray coating). The spray coating can be ultrasonic spray coating. The spray coating can be carried out using a dispenser having a single nozzle. Advantageously, having compatibility with such spray coating, the present apparatus and method are straightforward and effective in reducing catalyst (e.g. platinum) loading for fuel cell applications. Spray coating provides a precise loading and homogeneous distribution of catalyst (e.g. platinum) on a designated area of the membrane with no significant lost and/or wastage of the catalyst. Conversely, catalyst may be easily lost and/or pinhole defects may occur in traditional decal transfer method. An example of spray coating is ultrasonic spray coating. Advantageously, the present apparatus and method are compatible with ultrasonic spray coating, which produces finer droplets size that prevents undesirable agglomeration of catalyst particles (and thus a thinner layer of catalyst can be obtained) as compared to traditional spray coating method such as air-spray coating, thereby reducing catalyst loading

without compromising catalytic performance of a membrane of the present disclosure when used in a fuel cell.

5 [0025] The present apparatus and method also circumvent any possibility of defects that tends to arise in the traditional approach of decal transfer of electrocatalyst from a substrate to the membrane in the process. With regard to the traditional multiple spray coating approach, the present apparatus and method are considerably less time consuming and simpler without the use of multiple spray nozzles nor to form multiple catalyst layers.

10 [0026] Advantageously, the present method, which involves the present apparatus, can be used to manufacture various catalyst coated membrane for different fuel cell applications, such as air-cooled or water-cooled proton exchange membrane fuel cell (PEM), and direct methanol fuel Cell (DMFC), etc.

15 [0027] Details of various embodiments of the present apparatus and method, and advantages associated with the various embodiments are now described below. Where the embodiments and advantages are described in the examples section further hereinbelow, they shall not be iterated for brevity.

20 [0028] The present disclosure describes an apparatus for manufacturing a catalyst coated membrane. The apparatus comprises a first element configured to receive a membrane. In various non-limiting embodiments, the apparatus may comprise the first element configured to have a membrane arranged thereon or arranged therein. In various embodiments, the apparatus may comprise a second element co-operable with the first element to secure the membrane to the apparatus, wherein the first element and the second element are detachable from each other when not in use, and when in use are configurable to be arranged in a manner which (i) secures the membrane to the first element and the second element, and (ii) for vacuum suction to be applied to the membrane. The vacuum suction may be applied within the first element and/or the second element. By exposing the membrane to the vacuum suction, this helps secure the membrane to the first element and the second element.

30 [0029] In certain non-limiting embodiments, the second element may be arranged in the first element. For understanding, FIG. 3A to 3B and FIG. 4B may be referred to for non-limiting examples of the arrangement of the first and second elements in such embodiments of the apparatus. In certain non-limiting embodiments, the second element may be arranged on the first element. For understanding, FIG. 5 may be referred to for non-limiting examples of the arrangement of the first and second elements in such embodiments of the apparatus.

35 [0030] In various embodiments, the apparatus may be operably coupled to a vacuum suction module. The vacuum suction module is operable to apply suction vacuum on the membrane so as to secure the membrane to the apparatus, for example, to the first element and/or the second element of the apparatus.

40 [0031] In certain non-limiting embodiments, the first element and the second element may be formed of a polymeric material or a metallic material. In such non-limiting embodiments, the polymeric material may comprise acrylic, polycarbonate, or polyester as non-limiting examples. In such non-limiting embodiments, the metallic material may comprise aluminum or stainless steel as non-limiting examples.

45 [0032] In certain non-limiting embodiments, the first element may comprise an area demarcated for the second element and/or membrane to be arranged therein. In such non-limiting embodiments, there may be an instance where the second element and the

membrane are arranged within the first element, with the membrane arranged on the second element.

[0033] In certain non-limiting embodiments, the second element may comprise holes through which the vacuum suction may be applied.

5 [0034] In certain non-limiting embodiments, the first element and the second element may be configurable to have the membrane sandwiched between the first element and the second element.

[0035] In certain non-limiting embodiments, the first element and the second element may each be configured as a frame having an opening for a catalyst ink to be deposited
10 on the membrane secured to the first element and the second element.

[0036] In certain non-limiting embodiments, the first element and the second element may comprise a magnetizable material or a magnetized material. In such non-limiting embodiments, the apparatus may be operably coupled to (i) one or more electromagnets; and/or (ii) a heating module. The operation of the one or more
15 electromagnets and the heating module are already described in the examples section further hereinbelow and hence shall not be iterated for brevity.

[0037] The present disclosure also describes a method for manufacturing a catalyst coated membrane. Embodiments and advantages described for the present apparatus of the first aspect can be analogously valid for the present method subsequently described
20 herein, and vice versa. Where the various embodiments and advantages have already been described above and in the examples section further hereinbelow, they shall not be iterated for brevity.

[0038] The method may comprise providing a membrane, securing a membrane to the apparatus described in various embodiments of the first aspect, and depositing a catalyst ink containing catalyst particles onto the membrane.
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[0039] In various embodiments, securing the membrane to the apparatus may comprise arranging the second element to (e.g. arrange in or arrange on) the first element.

[0040] In various embodiments, securing the membrane to the apparatus may comprise arranging the membrane on the second element.

30 [0041] In certain non-limiting embodiments, securing the membrane may comprise arranging the membrane on the first element prior to arranging the second element.

[0042] In certain non-limiting embodiments, securing the membrane may comprise arranging the second element on the membrane to sandwich the membrane between the first element and the second element. In such non-limiting embodiments, securing the
35 membrane may comprise operating one or more electromagnets to have the first element and the second element clamp onto the membrane. In such non-limiting embodiments, depositing the catalyst ink may comprise operating a heating module to heat the membrane during depositing the catalyst ink.

[0043] In various embodiments, securing the membrane may comprise operating a vacuum suction module to have vacuum suction applied to the membrane.
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[0044] In various embodiments, depositing the catalyst ink may comprise spray coating the catalyst ink on one side of the membrane, and then the other side of the membrane.

[0045] The word “substantially” does not exclude “completely” e.g. a composition which is “substantially free” from Y may be completely free from Y. Where necessary,
45 the word “substantially” may be omitted from the definition of the present disclosure.

[0046] In the context of various embodiments, the articles “a”, “an” and “the” as used with regard to a feature or element include a reference to one or more of the features or elements.

[0047] In the context of various embodiments, the term "about" or "approximately" as applied to a numeric value encompasses the exact value and a reasonable variance.

[0048] As used herein, the term "and/or" includes any and all combinations of one or more of the associated listed items.

- 5 [0049] Unless specified otherwise, the terms "comprising" and "comprise", and grammatical variants thereof, are intended to represent "open" or "inclusive" language such that they include recited elements but also permit inclusion of additional, unrecited elements.

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Examples

[0050] The present disclosure relates to an apparatus for manufacturing a catalyst coated membrane (CCM). The present disclosure relates to a method for manufacturing the catalyst coated membrane. The method involves use of the apparatus. The method may be interchangeably referred to as a process in the present disclosure.

- 15 [0051] The method can involve spray coating of a catalyst onto a membrane, whereby the membrane can be secured using the apparatus during the spray coating process. The apparatus developed may have a configuration of a jig, that is to say, the apparatus is configured to control and/or confine the location and/or motion of an item or a part of the item. The item may be a membrane or any substrate which the apparatus can accommodate.

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[0052] The catalyst coated membrane may be configured as part of a fuel cell, a fuel cell stack, or any electrical system. The electrical system may include a fuel cell and/or a fuel cell stack. Non-limiting examples of a fuel cell and a fuel cell stack may include an air-cooled or water-cooled proton exchange membrane fuel cell (PEMFC), a direct methanol fuel cell (DMFC), an alkaline fuel cell (AFC), and a solid oxide fuel cell (SOFC).

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[0053] Advantageously, the method and apparatus are operable for batch production of a fuel cell, a fuel cell stack, and any electrical system incorporating a fuel cell or a fuel cell stack. Non-limiting examples of the fuel cell and fuel cell stack are mentioned above. Understandably, a catalyst coated membrane manufactured using the method and apparatus can be produced under a batch operation.

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[0054] The present method and apparatus are described in further details, by way of non-limiting examples, as set forth below.

[0055] Example 1: General Introduction of Method and Apparatus

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[0056] Various examples of the present disclosure relate to a process for manufacturing a catalyst coated membrane (CCM) using spray coating technique.

[0057] In certain non-limiting embodiments, the process can involve ultrasonic spray coating. As one non-limiting example, the process can involve spraying catalyst ink onto a membrane via a single nozzle, which is operably straightforward and advantageously effective for reducing catalyst (such as platinum) loading for fuel cell applications.

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[0058] In various embodiments, the catalyst ink may comprise a catalyst, an ionomer, and one or more solvents. Non-limiting examples of the catalyst may include platinum, ruthenium, osmium, palladium, or an alloy thereof. Non-limiting examples of the ionomer may include a proton-conducting polymer such as a perfluorinated polymer or sulfonated perfluorinated polymer. The one or more solvents may be an organic or aqueous solvent. The organic solvent may be miscible with water. The organic solvent may be an alcohol. In any case, non-limiting examples of the one or more solvents may

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include water, alcohol, or a mixture thereof. The alcohol may be a C₁₋₄ alcohol, such as but not limited to, methanol, ethanol, propan-1-ol, or propan-2-ol. The catalyst ink may be subjected to homogenization (e.g. by magnetic stirring, shear mixing, or ball milling) followed by ultrasonication prior to spray coating on the membrane.

5 [0059] Various examples of the present disclosure describe for embodiments of the apparatus. In other words, the present disclosure describes for at least two non-limiting examples of the apparatus and their configurations. The apparatus is operably configured, for example, to secure and smoothen a membrane, such as an ionomer membrane.

10 [0060] In certain non-limiting embodiments, the apparatus can include a “jig” configuration operable to secure a membrane (or any membrane substrate or any substrate). The membrane substrate, in the context of the present disclosure, refers to a layer that can be combined with a membrane to form a resultant membrane, wherein the membrane substrate supports the membrane (e.g. provide structural support and/or
15 mechanical strength). In such embodiments, generally, the apparatus includes a polymeric (e.g. acrylic) jig holder (as a first element) configured to secure any membrane (or any membrane substrate or any substrate). The first element may be configured with an area that is demarcated for a membrane (or any membrane substrate or substrate) and/or a second element to be arranged therein. In such embodiments, the
20 apparatus includes another detachable polymeric (e.g. acrylic) jig (as the second element) which has holes. In such embodiments, the first element and the second element are configurable to be arranged together, and removed from each other (when needed) without any damage to both elements and any membrane (or any membrane substrate or any substrate). Even after removal, the first and second elements can be
25 arranged together again. The second element, i.e. the polymeric jig having holes, is configured to secure any membrane (any membrane substrate or substrate) via vacuum applied through the holes, for example, during a catalyst ink spraying step of the present method. Said differently, the second element having the holes helps to hold any membrane (any membrane substrate or substrate) in place. Also, the second element is
30 co-operable with the first element to have any membrane (any membrane substrate or substrate) held in place, for example, during a catalyst ink spraying step of the present method.

[0061] In certain non-limiting embodiments, the apparatus can include a “jig” configuration for securing a membrane (or any membrane substrate or any substrate).
35 The membrane substrate, in the context of the present disclosure, refers to a layer that can be combined with a membrane to form a resultant membrane, wherein the membrane substrate supports the membrane (e.g. provide structural support and/or mechanical strength). In such embodiments, generally, the apparatus can include a clamp “jig” configured to secure any membrane (or any membrane substrate or any
40 substrate), for example, during a catalyst ink spraying step of the present method. The clamp “jig” can be made of any magnetized (or magnetizable) material. Embodiments related to such clamp “jig” is described in examples 3A and 3B below in more detail.

[0062] Example 2A: One Non-Limiting Example of the Present Apparatus

45 [0063] Certain non-limiting embodiments of the apparatus of the present disclosure is described in this example and illustrated in FIG. 3A to 3C and 4A to 4B.

[0064] FIG. 3A shows the first element of the apparatus. The first element can be made of a polymeric material (e.g. acrylic, polycarbonate, polyester) or a metallic (e.g. aluminum, stainless steel) material. The material of the first and second elements may

depend on the operating temperature (e.g. metallic material is preferred for higher temperature process). The first element may be referred to as a “jig” holder as it is configured for a membrane (or any membrane substrate or substrate) and a second element to be arranged therein. The first element has an area demarcated for the membrane and the second element to be arranged therein. The second element and the membrane may be housed within the first element. The demarcation helps align the membrane (or any membrane substrate or substrate) arranged therein with a second element and protect the membrane from being deposited with too much catalyst, for example, when the membrane is sprayed with a catalyst ink containing catalyst particles to be coated on the membrane.

[0065] FIG. 3B shows the second element of the apparatus. The second element can be made of a polymeric (e.g. acrylic, polycarbonate, polyester) material or a metallic material (e.g. aluminum or stainless steel) as mentioned above. The second element may be referred to as a “jig” with holes. The second element can be arranged in the first element with the membrane placed on the second element. The second element and the first element are co-operable to secure the membrane in place. The second element provides additional support to have the membrane secured in place as vacuum suction (from a vacuum section module) can be applied through the holes of the second element. This prevents the membrane from unnecessary movement, for example, when a membrane arranged on the second element experiences a force from a catalyst ink that is sprayed thereon.

[0066] FIG. 3C shows a membrane sandwiched between two protective layers (referred to as top and bottom protective layers). The membrane can be a nafion membrane (e.g. a proton exchange membrane abbreviated as PEM). The protective films act as an electronic insulator and reactant barrier from air and hydrogen gas, etc. The protective films are removable from the membrane prior to coating catalyst particles thereon.

[0067] The membranes used in PEM fuel cells, can include but are not limited to, perfluorosulfonic acid (PSFA) membranes containing sulphonic acid groups or derivatives of sulphonic acid groups. Among these membranes, the thickness of such membrane used in PEM fuel cells may vary significantly from 25.4 μm to 254 μm . A thinner membrane is suitable for instances where lower protonic resistance is desired, but a challenge lies in handling such thin membranes and their tendency to swell when in contact with the catalyst ink.

[0068] The first element and the second element of the apparatus as shown in FIG. 3A and 3B are configurable to secure membranes of different thicknesses and have the advantages of (i) being simple and low-cost design (also scalable in size), (ii) enable coating of both sides of the membrane with no alignment issues, and (iii) restrict swelling of membrane during the spraying of a catalyst ink.

[0069] A method of using the apparatus demonstrated in this example is described in detail below in example 2B.

[0070] Example 2B: One Non-Limiting Example of the Present Method Operated with Apparatus of Example 2A

[0071] The present example describes a method of the present disclosure, wherein the method is carried out using the apparatus of example 2A. Various steps of the method are illustrated, by way of non-limiting examples, in FIG. 4A. The arrangement of the first element, the second element and the membrane in certain steps of FIG. 4A are shown in FIG. 4B.

[0072] **Step 400:** Firstly, a membrane (or any membrane substrate or substrate) was cut into a suitable shape (e.g. square as depicted in FIG. 3C). The size of the membrane may be slightly smaller (about 5%) than the second element of the apparatus (depicted in FIG. 3B). Advantageously, even if the membrane is smaller than the second element, the first and second elements are still able to secure (e.g. restrict motion) the membrane during, for example, spraying of a catalyst ink thereon. Next, a protective layer of the membrane was removed.

[0073] **Step 402:** The second element, as shown in FIG. 3B (also see FIG. 4B), was arranged in the first element of the apparatus (shown in FIG. 3A), wherein the first and second elements are arranged to form the apparatus. Next, the membrane from step 400 was placed on top of the second element.

[0074] **Step 404:** The membrane was secured to the first element with an adhesive tape at all four edges of the membrane. The taping was done to one side of the membrane in a manner that minimizes covering the membrane surface. The adhesive tape is not only to secure the membrane, but also to render the membrane surface even out so as to be conducive for a catalyst ink to be coated evenly on the membrane.

[0075] **Step 406:** The secured membrane with the elements were placed in a spray chamber with a heating bed operably coupled to a source operable to provide vacuum suction, and the catalyst ink was sprayed on one side of the membrane.

[0076] **Step 408:** The sprayed membrane with the elements were removed from the spray chamber and flipped over. Prior to flipping, the earlier protective layer removed in step 400 may be placed on the surface of the membrane containing the catalyst ink and taped thereon. The second element (also shown in FIG. 3B) was removed from the membrane and the first element after flipping so as to prepare for spraying the other side of membrane with the catalyst ink.

[0077] **Step 410:** The other protective layer of the membrane was removed, exposing the other side of the membrane.

[0078] **Step 412:** The secured membrane with the elements were placed back into the spray chamber. The catalyst ink was sprayed on the other side of the membrane.

[0079] **Step 414:** The membrane having both sides coated with catalyst (i.e. catalyst coated membrane) was attained. The sprayed membrane and the first element were removed from the spray chamber and dried at room temperature (e.g. 20 to 40°C, 20 to 30°C, 30 to 40°C) for about 24 hours. The adhesive tape was removed from the catalyst coated membrane, followed by the catalyst coated membrane removed from the first element.

[0080] **Step 416:** This step shows a top view of the catalyst coated membrane (left image) and a cross-sectional view (right image) of the catalyst coated membrane. If needed, the one or more protective layers that were removed may be used to cover the one or more surfaces of the catalyst coated membrane so as to protect the catalyst coated membrane and removed later for further use.

[0081] The weight of the membrane was recorded before and after the coating to calculate the amount of catalyst loaded on the membrane. The first and second elements used in the present example are formed of a polymeric material (e.g. acrylic, polycarbonate, polyester). Alternatively, the first and second elements can be formed of a metallic material (e.g. aluminum, stainless steel). The material of the first and second elements may depend on the operating temperature (e.g. metallic material is preferred for higher temperature process).

[0082] **Example 3A: Another Non-Limiting Example of the Present Apparatus**

[0083] Certain non-limiting embodiments of the apparatus of the present disclosure are described in this example and illustrated in FIG. 5.

[0084] In the present example and referring to left image of FIG. 5, the apparatus includes two clamp jigs (i.e. also referred to as the first element and the second element). One of the clamp jigs may be used as the bottom clamp jig (first element) and the other as the top clamp jig (second element). A membrane can be arranged between the first and second elements for spray coating with a catalyst ink. A vacuum suction module can be operably coupled to the first element of the apparatus. The vacuum suction module may be referred herein to as “vacuum suction base” as it provides stability to the first and second elements (and membrane) when placed thereon. The vacuum suction module may include or may be operably coupled to a heating module for providing heat to dry the membrane.

[0085] The first and second elements in this example may comprise or may be composed of magnetizable or magnetized material. In other words, in certain non-limiting embodiments, the first and second elements in this example may comprise or may be formed of magnetizable or magnetized material. In such embodiments, when the first and second elements are arranged as shown in right image of FIG. 5, one or more electromagnets that are placed proximal to the apparatus may be turned on (e.g. during spray coating of the catalyst ink) to increase the clamping force by the first and second elements on the membrane so as to prevent membrane from moving (e.g. slipping off) from the spraying force exerted by the catalyst ink. In certain non-limiting embodiments, the apparatus may be operably coupled to the one or more electromagnets. The one or more electromagnets may be distal from the heating module. In certain non-limiting embodiments, the one or more electromagnets may be housed in the vacuum suction module, and in such embodiments, the one or more electromagnets may be housed distal from the heating module.

[0086] Example 3B: Another Non-Limiting Example of the Present Method Operated with Apparatus of Example 3A

[0087] The present example describes a method of the present disclosure, wherein the method is carried out using the apparatus of example 3A. Various steps of the method are illustrated, by way of non-limiting examples, in FIG. 6.

[0088] **Step 600:** The clamp jig (bottom – i.e. first element) in FIG. 6 was first placed onto the vacuum suction module. This first element helps in positioning a membrane (or any membrane substrate or substrate) while the vacuum suction module provides suction to stabilize the membrane and to heat the membrane during the spraying process (e.g. spraying of catalyst ink containing catalyst particles). The vacuum suction module may reside in a spray chamber.

[0089] **Step 602:** A membrane was cut into a suitable (e.g. rectangle) shape as depicted in FIG. 6 with a size substantially similar to that of the first element. Next, a bottom protective layer of the membrane was removed, and the membrane was arranged onto the first element.

[0090] **Step 604a:** The vacuum suction module was turned on to have suction vacuum available to stabilize and secure the membrane to the first element.

[0091] **Step 604b:** Next, a top protective layer on the other side of the membrane was removed.

[0092] **Step 606a:** The clamp jig (top – i.e. second element) in FIG. 6 was arranged over the membrane. The first and second elements (also depicted in FIG. 5) are a magnetized pair to provide a clamping force on the membrane, which also helps in

securing the membrane when flipping to the membrane's reverse side for the spraying process.

[0093] **Step 606b:** Next, the heating in the vacuum suction module was turned on.

5 [0094] **Step 608a:** The one or more electromagnets configured (e.g. beneath) the vacuum suction module were turned on to increase the clamping force from the first and second elements so that the membrane was properly secured.

[0095] **Step 608b:** The catalyst ink was sprayed first on one side of the membrane.

10 [0096] **Step 610:** The vacuum suction module, the heating module, and the one or more electromagnets were then turned off. The first and second elements (held together – i.e. the apparatus) were lifted off the vacuum suction module.

[0097] **Step 612:** The first and second elements (held together) are flipped over to expose the reverse side of the membrane.

15 [0098] **Step 614:** The first and second elements (held together) were then placed onto the vacuum suction module. The vacuum suction module, the heating module, and the one or more electromagnets were turned on. The catalyst ink was sprayed on this reverse side of the membrane.

[0099] **Step 616:** The vacuum suction module, the heating module, and the one or more electromagnets were turned off. The catalyst coated membrane (CCM) having both sides coated with the catalyst was attained. The apparatus with the sprayed membrane was removed from the spray chamber and dried at room temperature (e.g. 20 to 40°C, 20 to 30°C, 30 to 40°C) for about 24 hours. The CCM was then removed from the first and second elements of the apparatus.

[00100] The weight of the membrane was recorded before and after the coating to calculate the amount of catalyst loaded on the CCM.

25 [00101] **Example 4: Summary and Applications**

[00102] The present disclosure describes for a process of spraying catalyst ink onto a membrane using the apparatus having a jig configuration that helps secure and smoothen the ionomer membrane while spraying the catalyst ink. As described above, non-limiting embodiments of the apparatus include a jig configuration to secure a membrane (or a membrane substrate or any substrate). Various non-limiting
30 embodiments of the apparatus and method operated with the apparatus are already described above in detail and shall not be iterated for brevity.

[00103] While the present disclosure has been particularly shown and described with reference to specific embodiments, it should be understood by those skilled in the art that various changes in form and detail may be made therein without departing from the spirit and scope of the present disclosure as defined by the appended claims. The scope of the present disclosure is thus indicated by the appended claims and all changes which come within the meaning and range of equivalency of the claims are therefore
35 intended to be embraced.

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CLAIMS

1. An apparatus for manufacturing a catalyst coated membrane, the apparatus comprising:
 - a first element configured to receive a membrane;
 - a second element co-operable with the first element to secure the membrane to the apparatus,wherein the first element and the second element are detachable from each other when not in use, and when in use are configurable to be arranged in a manner which
 - (i) secures the membrane to the first element and the second element, and
 - (ii) for vacuum suction to be applied to the membrane.
2. The apparatus of claim 1, wherein the second element is arranged in the first element or wherein the second element is arranged on the first element.
3. The apparatus of claim 1 or 2, wherein the apparatus is operably coupled to a vacuum suction module.
4. The apparatus of any one of claims 1 to 3, wherein the first element and the second element are formed of a polymeric material or a metallic material.
5. The apparatus of claim 4, wherein the polymeric material comprises acrylic, polycarbonate, or polyester, wherein the metallic material comprises aluminum or stainless steel.
6. The apparatus of any one of claims 1 to 5, wherein the first element comprises an area demarcated for the second element and/or membrane to be arranged therein.
7. The apparatus of any one of claims 1 to 6, wherein the second element comprises holes through which the vacuum suction is applied.
8. The apparatus of any one of claims 1 to 3, wherein the first element and the second element are configurable to have the membrane sandwiched between the first element and the second element.
9. The apparatus of any one of claims 1 to 3 and 8, wherein the first element and the second element are each configured as a frame having an opening for a catalyst ink to be deposited on the membrane secured to the first element and the second element.
10. The apparatus of any one of claims 1 to 3 and 8 to 9, wherein the first element and the second element comprise a magnetizable material or a magnetized material.
11. The apparatus of any one of claims 1 to 3 and 8 to 10, wherein the apparatus is operably coupled to
 - (i) one or more electromagnets; and/or
 - (ii) a heating module.

12. A method for manufacturing a catalyst coated membrane, the method comprising:
providing a membrane;
securing a membrane to the apparatus of any one of claims 1 to 11; and
depositing a catalyst ink containing catalyst particles onto the membrane.
13. The method of claim 12, wherein securing the membrane to the apparatus comprises arranging the second element to the first element.
14. The method of claim 12 or 13, wherein securing the membrane to the apparatus comprises arranging the membrane on the second element.
15. The method of claim 12 or 13, wherein securing the membrane comprises arranging the membrane on the first element prior to arranging the second element.
16. The method of claim 15, wherein securing the membrane comprises arranging the second element on the membrane to sandwich the membrane between the first element and the second element.
17. The method of claim 15 or 16, wherein securing the membrane comprises operating one or more electromagnets to have the first element and the second element clamp onto the membrane.
18. The method of any one of claims 15 to 17, wherein depositing the catalyst ink comprises operating a heating module to heat the membrane during depositing the catalyst ink.
19. The method of any one of claims 12 to 18, wherein securing the membrane comprises operating a vacuum suction module to have vacuum suction applied to the membrane.
20. The method of any one of claims 12 to 19, wherein depositing the catalyst ink comprises spray coating the catalyst ink on one side of the membrane, and then the other side of the membrane.