(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
26 June 2014 (26.06.2014)

WIPO | PCT

(10) International Publication Number
WO 2014/100333 A1

(51) International Patent Classification:
F28F 19/00 (2006.01) *F28G 7/00* (2006.01)
F28F 19/02 (2006.01)

(21) International Application Number:
PCT/US2013/076390

(22) International Filing Date:
19 December 2013 (19.12.2013)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
61/740,620 21 December 2012 (21.12.2012) US

(71) Applicant *(for SM, US only)*: **SHELL OIL COMPANY** [US/US]; One Shell Plaza, P.O. Box 2463, Houston, Texas 77252-2463 (US).

(71) Applicant *(for all designated States except US)*: **SHELL INTERNATIONALE RESEARCH MAATSCHAPPIJ B.V.** [NL/NL]; Carel van Bylandtlaan 30, NL-2596 The Hague (NL).

(72) Inventors: **AGARWAL, Akhil**; 6355 Madera Lane, Beaumont, Texas 77706 (US). **ZOETEMEIJER, Leendert Johannes Arie**; Lange Kleiweg 40, NL-2288GK Rijswijk (NL). **JOSHI, Himanshu**; 398 North Road, Chester, New Jersey 07930 (US).

(74) Agent: **WIRZ, Melody E.**; SHELL OIL COMPANY, One Shell Plaza, P.O. Box 2463, Houston, Texas 77252-2463 (US).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM,

[Continued on next page]

(54) Title: HEAT EXCHANGER AND METHOD OF IMPROVING A HEAT EXCHANGER

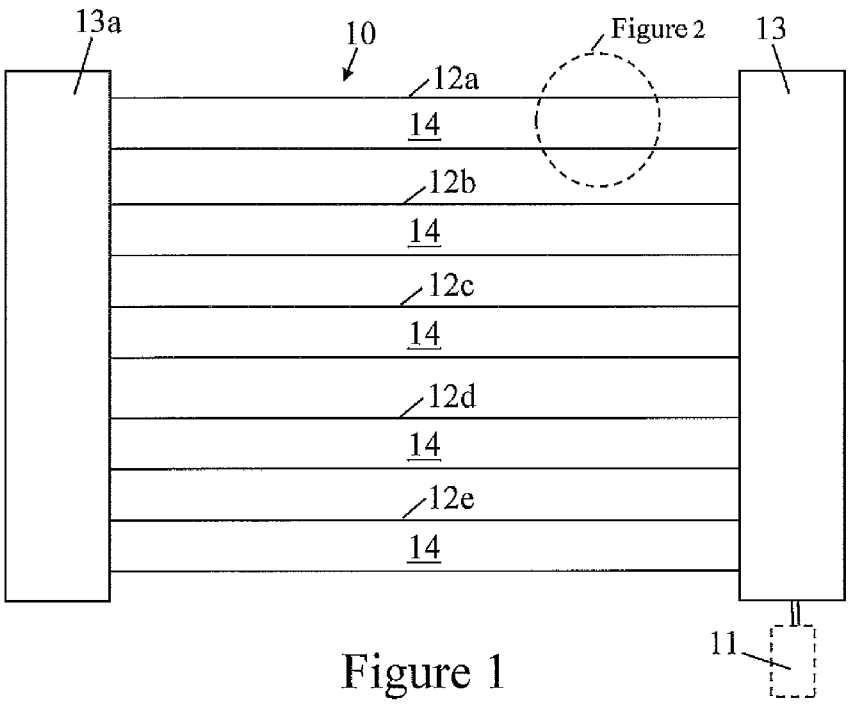


Figure 1

(57) Abstract: A heat exchanger including a wall and a hydrophobic material. The wall has an interior surface and an exterior surface. At least a portion of the exterior surface includes the hydrophobic material. Providing of the hydrophobic material on at least a portion of the exterior surface of the wall of the heat exchanger improves the efficiency of the heat exchanger.

WO 2014/100333 A1

TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

HEAT EXCHANGER AND METHOD OF IMPROVING A HEAT EXCHANGER

The present invention to a heat exchanger and a method of improving efficiency of a heat exchanger.

Heat exchangers are used in a number of industrial applications to transfer heat to or from a fluid before or after undergoing a process. An air-cooled heat exchanger is one type of heat exchanger, commonly used to cool a fluid to near ambient temperature. An air-cooled heat exchanger, also called an air cooler, typically uses air as a cooling medium. The air can be introduced to an exterior of a conduit holding the fluid to be cooled. In many cases, the air is moved across a bundle of conduits via fans, blowers, or other motive power or just by natural draft of the air-cooled heat exchanger. Thus, heat can be rejected from the fluid into ambient air surrounding the conduit. In some air coolers, the conduit has fins to provide additional surface area for heat transfer.

Particularly when the air-cooled or air-heated heat exchanger is employed in cold environments, ice may form as a result of buildup of condensation from water vapor present in air, or as a result of freezing rain, snow, or other precipitation. When such a sheet of ice forms between the air and the walls of the heat exchanger, the ice has a tendency to act as a thermal insulator, which can significantly reduce efficiency of the heat exchanger.

Various methods of addressing ice formation have been used in air-cooled heat exchangers. Some methods involve stopping operations for de-icing, which tends to be undesirable. Some methods have involved directly heating the walls of the heat exchanger to a point above freezing

via auxiliary heating coils, or co-current flow. An article “Natural Gas Regasification Technologies” by LT Hannah Kawamoto, which featured in the Proceedings Magazine of the Marin Safety & Security Council, Volume 65 No. 4, describes natural gas regasification technologies wherein a supplemental heat system is suggested to maintain effective use of ambient air vaporizers during colder weather conditions.

Such methods require capital expenditure and must be monitored. Additionally, the addition of heat to a process intended to cool is harmful to overall efficiency. Other methods have involved enclosing or sheltering the heat exchanger. These methods also involve capital expenditure and can prevent adequate access to the heat exchanger for maintenance and the like. Other methods still involve warming the ambient air by combining it with exhaust air prior to use as a cooling medium. Again, these methods are harmful to system efficiency.

When fins are present, the formation of ice can be even more difficult to address.

In accordance with a first aspect of the present invention, there is provided a heat exchanger comprising a wall having an interior surface and an exterior surface, wherein at least a portion of the exterior surface comprises a hydrophobic material.

In another aspect of the invention, there is provided a method of improving efficiency of a heat exchanger which method comprises providing a hydrophobic material on an exterior surface of the heat exchanger.

The invention will be further illustrated hereinafter by way of example only, and with reference to the non-limiting drawing in which:

Figure 1 schematically shows a top view of a heat exchanger wherein the invention is incorporated;

Figure 2 schematically shows an enlarged cross sectional of one tube of the heat exchanger of Figure 1; and

Figure 3 schematically shows a sessile drop of water on the exterior surface.

For the purpose of this description, a single reference number will be assigned to a line as well as a stream carried in that line. Same reference numbers refer to similar components. The person skilled in the art will readily understand that, while the invention is illustrated making reference to one or more a specific combinations of features and measures, many of those features and measures are functionally independent from other features and measures such that they can be equally or similarly applied independently in other embodiments or combinations.

It is presently proposed that an exterior surface of the wall of the heat exchanger comprises a hydrophobic material. The wall of the heat exchanger may be the fluid barrier that physically separates one fluid (e.g. ambient air, in the case of the heat exchanger being an ambient-air operated heat exchanger) from another fluid (e.g. a process fluid), while allowing transfer of heat between the one fluid and the other fluid.

The use of hydrophobic material is found to address the issue of ice on heat transfer surfaces, including fins, of a heat exchanger. The hydrophobic material reduces the presence of ice on the exterior surface. The hydrophobic material may inhibit ice formation on the exterior surface. The hydrophobic material may inhibit ice accumulation on the exterior surface. The hydrophobic

material may promote removal of ice from the exterior surface.

The wall of the heat exchanger of which the exterior surface comprises the hydrophobic material suitably is a tube wall of a tube arranged to carry the process fluid.

The exterior surface of the wall is suitably arranged to be exposed to ambient air, whereas the interior surface of the wall may be arranged to be exposed to a process fluid. This way the process fluid can be in indirect heat exchange contact with the ambient air. The use of the hydrophobic material on at least a portion of the exterior surface is particularly beneficial if the heat exchanger is an ambient-air operated heat exchanger. An ambient-air operated heat exchanger is a heat exchanger that is arranged to perform indirect heat exchange between a fluid, typically a process fluid, and air from the ambient. The heat exchanger may thus be an air-cooled heat exchanger, which is configured to cool the fluid against the ambient air. Alternatively, the heat exchanger may be an air-heated heat exchanger, which is configured to heat the fluid against the ambient air.

The hydrophobic material may have a contact angle of more than 90° for water on the hydrophobic material. In such cases the exterior surface has anti-wetting properties for water. The hydrophobic material is beneficial whenever moisture can condense on the exterior surface. When moisture condenses, the anti-wetting property of the exterior surface prevents the formation of a liquid film on the exterior surface. As a result, more of the exterior surface is kept exposed to vapor which generally benefits the efficiency of the heat exchanger. In some cases the hydrophobic properties enhance condensation. Accumulated drops of water may fall

off and/or be dragged off the exterior surface under influence of the air flow.

The benefits of the hydrophobic material on the exterior surface may especially come out when the exterior surface is exposed to air having a temperature of less than 0 °C. When condensation of moisture, for instance moisture from the air, occurs at temperatures near or below freezing, the hydrophobic material helps against the tendency to form undesirable sheets of ice, resulting in heat transfer by conduction instead of by convection. Ice formation on air-cooled heat exchangers operating in extremely cold climate or when there in cryogenic fluid flowing inside the tube severely affects the performance of the heat exchanger, leading to operational difficulty and reliability problems. These problems can be reduced by the proposed use of the hydrophobic material.

Preferably, the contact angle is between 90° and 150°.

Referring now to Figure 1, a heat exchanger 10 may have any number of heat transfer surfaces for providing the transfer of heat from one fluid to another fluid. Such heat transfer surfaces may include hollow tubes 12, through which the fluid to be heat exchanged flows. For ease of reference, this fluid will hereinafter be referred to as process fluid 14. However, in the broadest sense, the invention can be used to add heat to or remove heat from any fluid.

Other exemplary heat transfer surfaces include twisted tubes, grooved tubes, micro-fin tubes, other rounded and non rounded tubes, plates, or other types of walls. Similarly, when fins are present, such fins may be L footed, extruded, or embedded fins or other types of fins used in conventional air coolers or otherwise. In

Figure 1, the heat exchanger 10 is an air-cooled heat exchanger with heat transfer surfaces that include a number of tubes 12a-12e. The number of tubes 12a-12e may be arranged between two headers 13,13a. These headers 13,13a may assist in distributing the process fluid 14 over the respective tubes and receiving the process fluid 14 from the respective tubes.

As illustrated in Figure 2, a tube 12a may have a wall 16 with an interior surface 18 and an exterior surface 20. The interior surface 18 and an exterior surface 20 form part of the heat transfer surfaces.

The wall 16 may be constructed of a material useful in heat transfer, such as carbon steel, stainless steel, or other alloy materials. When cooling of the process fluid 14 is desired, the exterior surface 20 of the wall 16 may be in contact with another fluid (e.g., ambient air) that is cooler than the process fluid 14 on the opposite side of the wall 16. The other fluid will hereinafter be referred to as ambient air 22. Ambient air is certainly contemplated, but the invention has benefits for any fluid from which moisture can condense.

Thus, the process fluid 14 may flow within the tube 12a, and a portion of the process fluid 14 may contact the interior surface 18 of the wall 16, allowing for heat within the process fluid 14 to be transferred to the interior surface 18, through the wall 16, to the exterior surface 20. The heat may then be transferred from the exterior surface 20 of the wall 16 into the ambient air 22 contacting the exterior surface 20. When the ambient air 22 contacting the exterior surface 20 contains water vapor, it may be desirable to mitigate the formation, accumulation, or other presence of water on the exterior surface 20 of the wall 16.

In particular, when temperatures of the ambient air 22 contacting the exterior surface 20 are near the freezing point of the vapors therein, it may be desirable to reduce the presence of ice (i.e., solid forms of water, including but not limited to sheets of ice, snow, frost, sleet, and freezing rain) on the exterior surface 20 of the wall 16. Thus, it may be desirable to prevent the formation of ice on the exterior surface 20 of the wall 16. If ice formation occurs on the exterior surface 20 of the wall 16, for example via snowfall, it may be desirable to prevent the accumulation of further ice on the exterior surface 20 of the wall 16. Additionally, if ice formation occurs, it may be desirable to promote the removal of the ice from the exterior surface 20 of the wall 16. The temperature of the wall 16 may be low enough to maintain ice, or to provide for the formation of ice, whether due to low temperature on one side, low temperature on the other side, or low temperature on both sides of the wall 16. It is believed that when temperatures of the wall 16 are about 0° C or less, the inclusion of hydrophobic material at the exterior surface 20 of the wall 16 would reduce the presence of ice on the exterior surface 20 in those areas where the hydrophobic material is present. This might occur by one or more of: (1) inhibiting ice formation on the exterior surface 20, (2) inhibiting ice accumulation on the exterior surface 20, and/or promoting ice removal from the exterior surface 20. Thus, when hydrophobic material is provided on the exterior surface 20 of the heat exchanger 10 and is exposed to cooling medium (e.g., ambient air) at a temperature of less than the 0 °C, formation of ice may be reduced as compared to the heat exchanger 10 without a hydrophobic material on the exterior surface 20.

Some or all of the exterior surface 20 of the wall 16 may include the hydrophobic material. The hydrophobic material may be material with water repelling characteristics. A contact angle, defined as the angle Θ between a sessile water drop 31 and the exterior surface 20, in a three-phase contact point 32 where vapor, liquid water, and the (solid) exterior surface comprising the hydrophobic material coexist, may for example be between 90° and 150°. A contact angle of larger than 90° stimulates formation of droplets on the exterior surface and discourages spreading over the exterior surface to form a film. Specific hydrophobic materials may have a contact angle for water between 90° and 120°, while other materials useful for the exterior surface 20 of the wall 16 may have a contact angle between about 120° and 150°. Hydrophobic materials in the form of super-hydrophobic materials may be used, in which case the corresponding contact angle may be 150° or greater.

The hydrophobic material may include silicon based materials such as organosilane epoxy, polymethylsilsesquioxane, polysilazane, SiO_2, epoxy silicate, siloxane.

The wall 16 may be integrally formed with the hydrophobic material, or the hydrophobic material may otherwise be provided in a way that the hydrophobic material is exposed to the ambient air 22 contacting the exterior surface 20. Suitably, wall 16 comprises a substrate 17, whereby the hydrophobic material forms a coating 24a on the substrate 17.

The hydrophobic material may incorporate a fluorinated coating to achieve the hydrophobicity. While the hydrophobicity may be the result of surface chemistry, the hydrophobic material may derive some or

all of the hydrophobicity from the mechanical or structural configuration or pattern of the surface. The hydrophobic material may be obtained from Aculon, Microphase, Luna Innovations, Lotus Leaf Coatings, or Applied MST. Characteristics to consider when selecting the hydrophobic material may include adhesion to the substrate (e.g., carbon steel), contact angle, temperatures and pressures under which the coating can operate, thickness, and how the coating is applied. The hydrophobic material may be resistive to accumulation of water, due to the hydrophobic (i.e., water repelling) properties. The hydrophobic material may prevent film formation on the exterior surface 20 that would otherwise eventually form ice. Additionally, the hydrophobic material may prevent formed ice from sticking to the exterior surface 20 of the wall 20. Thus the ice eventually falls down to the ground in a pan or small chunks flow out with the air. Super-hydrophobic materials may greatly reduce frosting potential of the heat exchanger 10.

The hydrophobic material may be applied on walls of heat exchangers which have in use over a period of time or to walls 16 of newly fabricated heat exchangers, and the method of application may be selected accordingly.

As illustrated, a portion 29a of the exterior surface 20 of the wall 16 may be coated with the hydrophobic material, while other portions 29b of the exterior surface 20 of the wall 16 may not be coated with the hydrophobic material. Any or all of the exterior surface 20 of the wall 16 may comprise hydrophobic material, whether formed via coating 24a, 24b, or otherwise. The hydrophobic coating 24a may be provided via spray coating, dipping, or brushing. For example, a vacuum

chamber may be used to apply a vapor deposition polymerization coating. Notably, however, the method of the application of the coating 24a is not thought to be as critical as the surface chemistry of the coating 24a.

The amount and placement of hydrophobic material on the exterior surface 20 of the heat exchanger 10 will depend on a number of factors. For example, when the heat exchanger 10 is air-cooled and is positioned outdoors, upper portions of the exterior surface 20 may be coated or otherwise provided with hydrophobic material to reduce the presence of weather-induced ice (e.g., snow, freezing rain, frost, etc.) on the exterior surface 20. Depending on the particular conditions at the site, and the shape of the exterior surface 20, anywhere between about 10% and about 100% of the exterior surface 20 may be provided with the hydrophobic material. For example, when the majority of the exterior surface 20 is rounded and exposed to the elements, at least 25% of the exterior surface 20 may have the hydrophobic material. When portions of the exterior surface 20 are shielded from the elements, a smaller portion may have the hydrophobic material. Likewise, some conditions may dictate a larger portion of the exterior surface 20 have the hydrophobic material. For example, the ends might not have the hydrophobic material, or the hydrophobic material may leave a gap where abrasion would occur, but other surfaces may have the hydrophobic material.

When the hydrophobic material is applied as a coating 24a, the thickness of the layer formed by the coating 24a is preferably less than 5 μm. Such thin layers do not impose a significant impact on heat transfer rate through the wall 16, and any impact may be offset by the benefits that the hydrophobic properties have. In one example,

commercially available coatings have been applied with a thickness of about 2 μm. Thinner coatings, such as nano-coatings which can have a thickness of between one and three orders of magnitude less, are currently subject to being developed for application on heat exchange surfaces.

Additional or alternative sections of hydrophobic material may be used in conjunction with a heat exchanger 10 having one or more fins 26. Such fins 26 may form part of the wall 16 and the exterior surface of the wall 16. As illustrated in Figure 2, such fins 26 may extend away from the interior surface 18. Each fin 26 may have an interior surface 28, and part of the exterior surface, indicated at 30 in Figure 2, forms part of the fin 26. Heat transfer properties may be similar to those described above with respect to the heat transfer surfaces the wall 16. The fins 26 may be constructed from similar materials as the wall 16 of the heat exchanger 10, or different materials such as aluminum, copper, or other metals or alloys may be used. Each fin 26 may extend outward from the exterior surface 20, such that the exterior surface 30 of the fin 26 extends from the exterior surface 20 of the wall 16, and the interior surface 28 of the fin 26 engages the exterior surface 20 of the wall 16. Other fin configurations may be used, so long as the fins 26 provide heat transfer properties.

When present, the fins 26 may include internal fins, external fins, microgrooves, or any other configuration designed to enhance heat transfer characteristics. The fin pitch of the tubes 12 may be optimized to reduce the possibility of ice accumulation due to bridging.

As with the exterior surface 20 of the wall 16, a portion of the exterior surface 30 of the fin 26 may be

coated or otherwise provided with the hydrophobic material as illustrated in Figure 2 by additional section of hydrophobic coating 24b. Likewise, the portion of the fins 26 having the hydrophobic material may depend on any of a number of factors. Further, one fin 26 or wall 30 of the heat exchanger 10 may be wholly or partly provided with the hydrophobic material while another fin 26 or wall 20 may have little or no hydrophobic material. Thus, any portion of the entire exterior surface 20, 30 of the heat exchanger 10 may be provided with the hydrophobic material in any of a number of ways. For example, the exterior surface 30 of the fins 26 may each be provided with hydrophobic material in different portions, while the entire exterior surface 20 of the wall 16 lacks hydrophobic material, or vice versa. Similarly, at least 25% of the exterior surface 30 of the fin 26 may have hydrophobic material and at least 25% of the exterior surface 20 of the wall 16 may have hydrophobic material.

Inclusion of hydrophobic material on exterior surfaces 20, 30 of the heat exchanger 10 are believed to inhibit formation and/or accumulation of ice as well as promote removal of ice already in place on the exterior surfaces 20, 30. Thus, when used alone, the hydrophobic material may provide a cost effective and low-maintenance alternative to conventional methods of preventing ice formation and accumulation.

Further, when used in conjunction with other conventional or unconventional methods, the use of hydrophobic material may provide enhanced results. For example, ultrasonic or other vibration, heating, or other methods configured to energize or otherwise remove materials from a heat exchange surface may be coupled with the hydrophobic material to provide an improved

method for addressing ice formation. Devices to provide ultrasonic vibration may be obtained from Morko or Koltso Energy. Such devices may be attached to the tube sheet of the air cooler or other structural parts from where vibration can be transmitted to the walls 16 or to any surface of the heat exchanger 10. An optional vibrator 11 for this purpose is schematically indicated in Figure 1. In the example of Figure 1, the optional vibrator 11 is suitably configured in physical contact with header 13, but other configurations are possible. Further, the vibration may be provided in a controlled manner to enhance results without risking damage due to excessive movement of the heat exchanger tubes.

The use of hydrophobic material on the exterior surface 20, 30 of the heat exchanger 10 may allow for improved efficiency. In particular, a method of improving efficiency of a heat exchanger 10 may include providing a hydrophobic material on an exterior surface 20, 30 of the heat exchanger. The hydrophobic material useful in such a method may include any of the materials described above. The hydrophobic material may reduce the presence of ice on the exterior surface, thereby improving efficiency, whether the heat exchanger 10 is an air-cooled or other type of heat exchanger 10 in which a cooling medium containing water vapor is used to cool the process fluid 14. The exterior surface 20, 30 of the heat exchanger 10 with hydrophobic material may be exposed to a cooling medium (e.g., ambient air) having a temperature of less than 0 °C. The hydrophobic material may reduce presence of ice as compared to a similar design without hydrophobic material. For example, the hydrophobic material may inhibit formation of ice on the exterior surface 20, 30. Alternatively, the hydrophobic material

may inhibit accumulation of ice on the exterior surface 20, 30. Further, the hydrophobic material may promote removal of ice from the exterior surface 20, 30 by preventing any ice present on the exterior surface 20, 30 from remaining in place. When ice is present on the exterior surface 20, 30 and hydrophobic material is present, agitation of the ice may result in the ice easily moving away from the hydrophobic material and thus away from the exterior surface 20, 30 of the heat exchanger 10. For example, if ice were present on top of a tubular wall 16 coated with hydrophobic material, and that wall 16 were vibrated with a controlled amplitude and frequency, the ice may be inclined to easily move from position because of the hydrophobic material, and, if moved enough, the ice may fall downward under the force of gravity.

Methods of improving efficiency may include either constructing new heat exchangers 10 with hydrophobic material or retrofitting hydrophobic material on existing heat exchangers 10. In either instance, providing hydrophobic material may include providing a coating of hydrophobic material on an exterior surface 20 of a wall 16 of the heat exchanger 16. In some instances, at least 25% of the exterior surface 20 of the wall 16 may include the hydrophobic material. When fins 26 are present on the heat exchanger 10, the method may include providing a coating of hydrophobic material on an exterior surface 30 of a fin 26 extending from a wall 16 of a tube 12 of the heat exchanger 10. In some instances, at least 25% of the exterior surface 30 of the fin 26 is coated with the hydrophobic material.

Many modifications could be made while remaining within the spirit of this disclosure. For example, while

a single wall 16 has been specified, the teachings herein provide sufficient detail for modifications involving any heat exchange surface of a heat exchanger, including either interior or exterior surfaces contacting air having water vapor therein. Likewise, while an air-cooled heat exchanger is described in detail, the teachings herein also apply to other types of heat exchangers in which the cooling medium can include water vapor, particularly those where the air will contact a heat exchange surface having a temperature at or near 0 °C. Furthermore, while the description relates to the use of hydrophobic material to repel water, whether liquid or frozen, other materials may be used to repel other condensates in other applications. Thus, the teachings herein could be applied to other applications in which solid formation is undesirable in a heat exchange relationship. Similarly, while the use of hydrophobic materials on the walls and fins is explicitly included, other heat exchange surfaces may also be covered, coated, or otherwise include hydrophobic materials. Headers (e.g. headers 13,13a) may include hydrophobic materials. Finally, it may be desirable to provide hydrophobic materials selectively. For example, it may be desirable to coat or otherwise include hydrophobic materials on only surfaces inclined to collect ice in certain conditions. Such surfaces may be the top surfaces inclined to collect dew, frost, or other precipitation, or they may include bottom surfaces inclined to collect icicles. In some embodiments, the temperature of the wall 16 may be maintained at a temperature above 0 °C for ambient air temperatures down to -15 °C. At lower air temperatures, moisture (e.g., in the form of supercooled water, ice, snow, or other precipitation) may become rare

and wall and process temperatures may be reduced below the freezing point.

Some applications may use the hydrophobic materials on the walls of air-cooled heat exchangers in liquid natural gas (LNG) production plants in cold climates, such as arctic LNG plants, where air-cooled heat exchangers may be employed to cool refrigerants and other process fluids with extremely low temperature air at high relative humidity. For example, finned surface temperatures may fall below the freezing point of water and be exposed to arctic precipitation with the risk of frost and ice formation on the finned surface area. The use of hydrophobic materials on the heat exchanger wall can prevent or reverse blockage of airflow area that would otherwise significantly impact cooling performance and LNG production. Since there is no ice accumulation or frosting on the heat exchanger, the performance of the heat exchanger may remain consistent through all weather cycles and process conditions in which ice formation might otherwise take place.

While the examples set forth above relate to the use of ambient air being used to cool process fluid inside of a heat exchanger, the hydrophobic material may be used where ambient air is used to heat the process fluid inside the heat exchanger. For example, liquid natural gas vaporization or revaporization applications may utilize the hydrophobic material on one or more surfaces on which ice may form. Thus, the application of the teachings herein would also apply to an air heated heat exchanger.

The person skilled in the art will understand that the present invention can be carried out in many various ways without departing from the scope of the appended

claims. Many modifications and variations are possible in terms of the disclosed embodiments, configurations, materials, and methods without departing from their scope. Accordingly, the scope of the claims and their functional equivalents should not be limited by the particular embodiments described and illustrated, as these are merely exemplary in nature and elements described separately may be optionally combined.

C L A I M S

1. A heat exchanger comprising a wall having an interior surface and an exterior surface, wherein at least a portion of the exterior surface comprises a hydrophobic material.

2. The heat exchanger of claim 0, wherein the hydrophobic material has a water repelling character whereby a contact angle between a sessile water drop and the exterior surface comprising the hydrophobic material, in a three-phase contact point where vapor, water liquid and the hydrophobic material coexist, is between 90° and 150°.

3. The heat exchanger of claim 1 or 2, wherein the wall comprises a substrate and wherein the hydrophobic material forms a coating on the substrate.

4. The heat exchanger of claim 3, wherein the coating on the substrate forms a layer with a thickness of less than 5 μm.

5. The heat exchanger of any one of claims 1 to 4, wherein the exterior surface of the wall is arranged to be exposed to ambient air and wherein the interior surface of the wall is arranged to be exposed to a process fluid, in indirect heat exchange contact with the ambient air.

6. The heat exchanger of claim 5, wherein the wall is a tube wall of a tube arranged to carry the process fluid.

7. The heat exchanger of any one of claims 1 to 6, wherein the heat exchanger is an ambient-air operated heat exchanger.

8. The heat exchanger of any one of claims 1 to 7, wherein at least 25% of the exterior surface comprises the hydrophobic material.

9. The heat exchanger of any one of claims 1 to 7, wherein the exterior surface comprises a fin extending away from the interior surface, wherein at least 25% of the exterior surface that forms part of the fin comprises the hydrophobic material.

10. The heat exchanger of any one of claims 1 to 9, further comprising a vibrator configured to energize the wall of the heat exchanger.

11. A method of improving efficiency of a heat exchanger, comprising providing a hydrophobic material on at least a portion of an exterior surface of a wall of the heat exchanger.

12. The method of claim 11, wherein the wall comprises a substrate, and wherein said providing of said hydrophobic material comprises coating of the substrate with the hydrophobic material.

13. The method of claim 12, wherein forming a layer with the hydrophobic material with a thickness of less than 5 μm.

14. The method of any one of claims 11 to 13, further comprising vibrating the wall of the heat exchanger.

15. The method of any one of claims 11 to 14, wherein the heat exchanger is an air-operated heat exchanger.

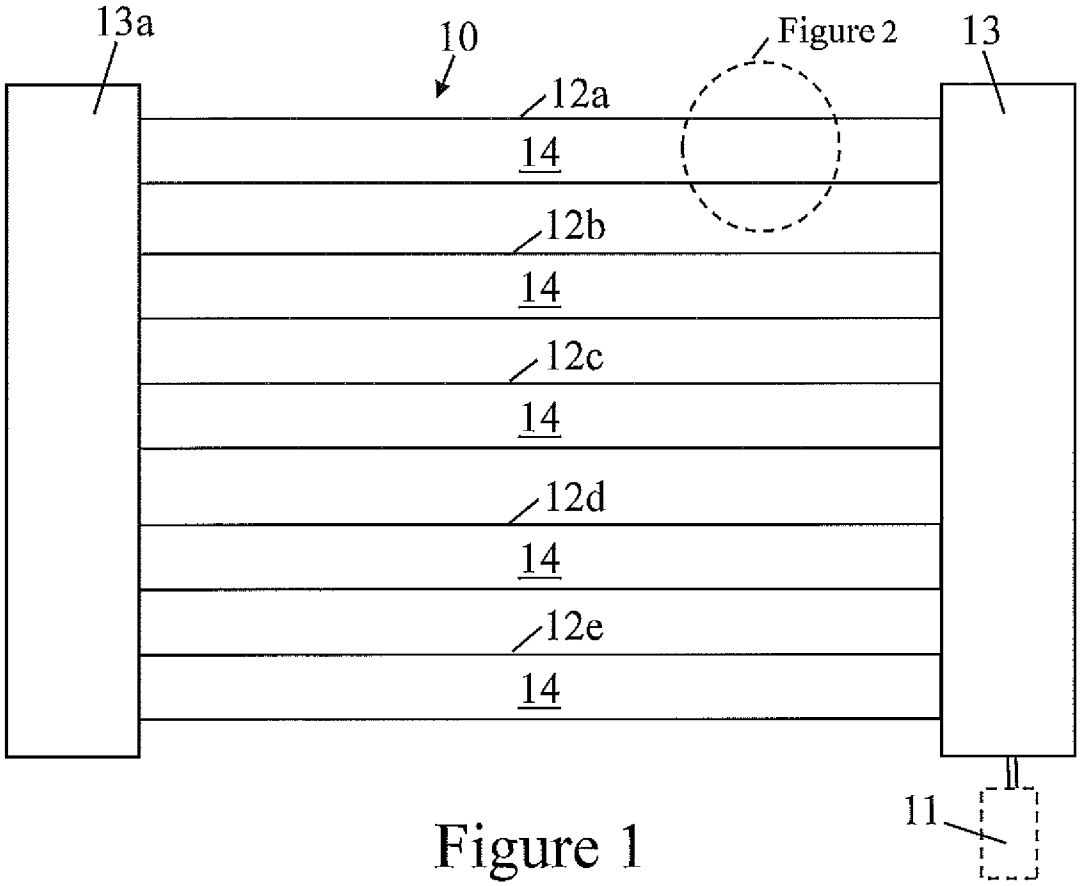


Figure 1

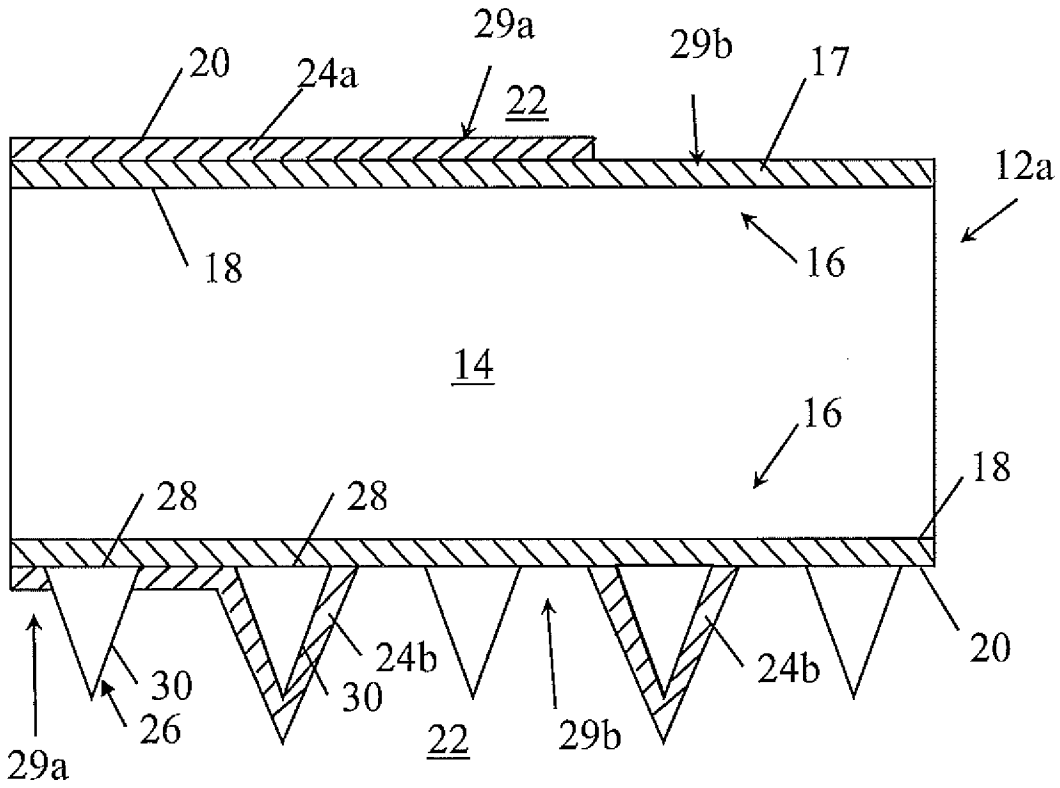


Figure 2

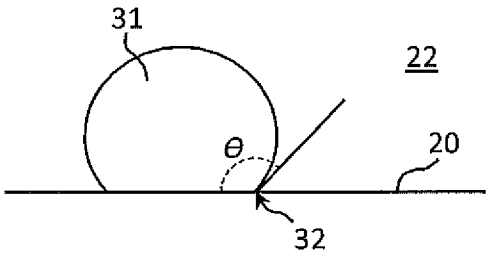


Figure 3

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2013/076390

A. CLASSIFICATION OF SUBJECT MATTER
INV. F28F19/00 F28F19/02 F28G7/00
ADD.

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)
F28F F28G

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6 971 248 B1 (WIGGS B RYLAND [US]) 6 December 2005 (2005-12-06) the whole document	1,3-15
X	US 7 886 558 B2 (WIGGS B R [US] WIGGS B RYLAND [US]) 15 February 2011 (2011-02-15) the whole document	1,3-15
X	EP 1 580 514 A1 (DAIKIN IND LTD [JP]) 28 September 2005 (2005-09-28) paragraphs [0198], [0201]	1-15
X	DE 20 2012 100838 U1 (ALPHA INNOTEC GMBH [DE]) 3 April 2012 (2012-04-03) the whole document	1,3,5-7, 10-12,15

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
24 March 2014	28/03/2014

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Vassoille, Bruno

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2013/076390

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 6971248 B1	06-12-2005	NONE	
US 7886558 B2	15-02-2011	NONE	
EP 1580514 A1	28-09-2005	AU 2003284696 A1	18-06-2004
		EP 1580514 A1	28-09-2005
		US 2005257558 A1	24-11-2005
		WO 2004048876 A1	10-06-2004
DE 202012100838 U1	03-04-2012	NONE	