US Patent & Trademark Office
Patent Public Search | Text View

United States Patent	12390770
Kind Code	B2
Date of Patent	August 19, 2025
Inventor(s)	Kolakaluri; Ravi et al.

Contactor system and method of operating contactor system

Abstract

A contactor system includes a plurality of contactor panels. Each contactor panel includes a frame member and a membrane array adapted to be received within the frame member. The membrane array defines a first end portion, a second end portion, and a plurality of hollow fibers. The contactor system also includes a first manifold in selective fluid communication with the first end portion of the membrane array of each contactor panel. The contactor system further includes a second manifold in direct fluid communication with the second end portion of the membrane array of each contactor panel. The contactor system includes a controller configured to provide selective fluid communication between the first manifold and the first end portion of the membrane array of each contactor panel.

Inventors:	**Kolakaluri; Ravi (Roseville, MN), Savvateev; Vadim N. (St. Paul, MN), Taylor; Gareth P. (Indian Trail, NC), Le Blanc; Shannon S. (White Bear Lake, MN), Zheng; Dian (Woodbury, MN), Badri; Brinda B. (Woodbury, MN), Nielsen; Paul A. (LaGrange, GA), Sengupta; Amitava (Charlotte, NC), Flom; Michael C. (Apple Valley, MN), Price; Timothy D. (Monroe, NC), Leatherdale; Catherine A. (Woodbury, MN)**
Applicant:	**3M INNOVATIVE PROPERTIES COMPANY** (St. Paul, MN)
Family ID:	**1000008764345**
Assignee:	**3M Innovative Properties Company (St. Paul, MN)**
Appl. No.:	**17/923073**
Filed (or PCT Filed):	**May 04, 2021**
PCT No.:	**PCT/IB2021/053748**
PCT Pub. No.:	**WO2021/245477**
PCT Pub. Date:	December 09, 2021

Prior Publication Data

Document Identifier	Publication Date
US 20230338899 A1	Oct. 26, 2023

Related U.S. Application Data

us-provisional-application US 63033313 20200602

Publication Classification

Int. Cl.: **B01D53/22** (20060101); **B01D53/26** (20060101); **B01D63/02** (20060101); **B01D63/08** (20060101); **F24F6/02** (20060101)

U.S. Cl.:

CPC **B01D63/026** (20130101); **B01D53/22** (20130101); **B01D53/268** (20130101); **B01D63/0822** (20220801); **F24F6/02** (20130101); B01D2257/80 (20130101); B01D2313/18 (20130101); B01D2313/221 (20220801); B01D2313/243 (20130101)

Field of Classification Search

CPC: B01D (63/026); B01D (63/0822); B01D (53/22); B01D (53/268); B01D (2313/221); B01D (2257/80); B01D (2313/18); B01D (2313/243); F24F (6/02)

References Cited

U.S. PATENT DOCUMENTS

Patent No.	Issued Date	Patentee Name	U.S. Cl.	CPC
4683101	12/1986	Cates	N/A	N/A
5556035	12/1995	Daub	N/A	N/A
5681368	12/1996	Rahimzadeh	N/A	N/A
6245454	12/2000	Gocho et al.	N/A	N/A
6502807	12/2002	Assaf et al.	N/A	N/A
6669177	12/2002	Shimanuki et al.	N/A	N/A
7866637	12/2010	Van Der Net	N/A	N/A
8317167	12/2011	Kim	N/A	N/A
8365530	12/2012	Zhang et al.	N/A	N/A
9541302	12/2016	Taylor et al.	N/A	N/A
9901190	12/2017	Resch	N/A	N/A
10021814	12/2017	Aoki et al.	N/A	N/A
10881046	12/2020	Tribelhorn	N/A	A01M 7/0089
12172129	12/2023	Burba	N/A	B01D 61/04
2003/0209480	12/2002	Kneifel et al.	N/A	N/A
2009/0095162	12/2008	Hargis et al.	N/A	N/A
2012/0304862	12/2011	Taylor et al.	N/A	N/A
2013/0340449	12/2012	Kozubal et al.	N/A	N/A
2017/0251590	12/2016	Kolb	N/A	B05B 13/005

2018/0135880	12/2017	Ghadiri Moghaddam et al.	N/A	N/A
2019/0212020	12/2018	Besant et al.	N/A	N/A
2019/0231600	12/2018	Locke	N/A	A61F 13/05
2019/0264301	12/2018	Burba	N/A	B01D 15/10
2019/0338440	12/2018	Banik	N/A	C25D 21/14
2021/0382533	12/2020	Heydari	N/A	G06F 1/206
2022/0071049	12/2021	Heydari	N/A	H05K 7/2079
2022/0111138	12/2021	Robinson	N/A	A61F 13/05
2022/0212144	12/2021	Burba	N/A	B01J 20/0281
2023/0240052	12/2022	Heydari	N/A	H05K 7/20263
2023/0413477	12/2022	Heydari	N/A	G06N 3/063
2024/0312778	12/2023	Banik, II	N/A	H01L 24/81

FOREIGN PATENT DOCUMENTS

Patent No.	**Application Date**	**Country**	**CPC**
101435608	12/2009	CN	N/A
201811367	12/2010	CN	N/A
102175457	12/2010	CN	N/A
205402992	12/2015	CN	N/A
105841326	12/2015	CN	N/A
205593083	12/2015	CN	N/A
106765746	12/2016	CN	N/A
106766997	12/2016	CN	N/A
106907809	12/2016	CN	N/A
206257764	12/2016	CN	N/A
106979573	12/2016	CN	N/A
107014012	12/2016	CN	N/A
206531124	12/2016	CN	N/A
107477720	12/2016	CN	N/A
206695290	12/2016	CN	N/A
105571020	12/2017	CN	N/A
207019212	12/2017	CN	N/A
108285185	12/2017	CN	N/A
108328828	12/2017	CN	N/A
108397838	12/2017	CN	N/A
105674452	12/2017	CN	N/A
207904067	12/2017	CN	N/A
106196230	12/2017	CN	N/A
109764736	12/2018	CN	N/A
2910568	12/1979	DE	N/A
102015005100	12/2015	DE	N/A
0236634	12/1990	EP	N/A
0650776	12/1996	EP	N/A
1292799	12/2002	EP	N/A
2113297	12/2013	EP	N/A
2892320	12/2018	EP	N/A
2887838	12/2021	EP	N/A
125927	12/2001	IL	N/A

63220026	12/1987	JP	N/A
08277640	12/1995	JP	N/A
10197016	12/1997	JP	N/A
2000140560	12/1999	JP	N/A
2001294402	12/2000	JP	N/A
2002075421	12/2001	JP	N/A
2009300029	12/2008	JP	N/A
2012149819	12/2011	JP	N/A
2015135230	12/2014	JP	N/A
20120106314	12/2011	KR	N/A
101344515	12/2012	KR	N/A
101405689	12/2013	KR	N/A
20200016444	12/2019	KR	N/A
2012077962	12/2013	SG	N/A
1998035399	12/1997	WO	N/A
2000011426	12/1999	WO	N/A
2003012357	12/2002	WO	N/A
2013191489	12/2012	WO	N/A
2014138851	12/2013	WO	N/A
2015134060	12/2014	WO	N/A
2018063849	12/2017	WO	N/A

OTHER PUBLICATIONS

Machine translate CN106907809A. cited by examiner
JP2000140560A_machine translate. cited by examiner
JPH10197016_machine translate. cited by examiner
Charles, “The Occurrence and Characterization of Fouling During Membrane Evaporative Cooling”, Journal of Membrane Science, Jul. 2008, vol. 319, No. 1-2, pp. 44-53. cited by applicant
Chen, “A Novel Evaporative Cooling System with a Polymer Hollow Fibre Spindle”, Applied Thermal Engineering, Mar. 2018, vol. 132, pp. 665-675. cited by applicant
International Search Report for PCT Application No. PCT/IB2021/053748, mailed on Aug. 5, 2021, 3 pages. cited by applicant
Jang, “Energy Demand Comparison Between Hollow Fiber Membrane Based Dehumidification and Evaporative Cooling Dehumidification Using TRNSYS”, Energies, 2018, vol. 11, pp. 1181/1-1181/15. cited by applicant
Johnson, “Analysis of Heat and Mass Transfer Phenomena in Hollow Fiber Membranes Used for Evaporative Cooling”, Journal of Membrane Science, Dec. 2003, vol. 227, No. 1-2, pp. 159-171. cited by applicant
Jradi, “Testing and Performance Analysis of a Hollow Fiber-Based Core for Evaporative Cooling and Liquid Desiccant Dehumidification”, International Journal of Green Energy, Apr. 2016, vol. 13, No. 13, pp. 1388-1399. cited by applicant
Laknizi, “Performance Analysis and Optimal Parameters of a Direct Evaporative Pad Cooling System Under the Climate Conditions of Morocco”, Case Studies in Thermal Engineering, Mar. 2019, vol. 13, (100362) 11 Pages. cited by applicant
Kobayashi H., Development of compact and high-performance dehumidifying system for air conditioning system using liquid desiccant and moisture permeable membrane, Grants-in-Aid for Scientific Research Report of Research Achievements, May 16, 2017. cited by applicant

Primary Examiner: Shumate; Anthony R

Background/Summary

CROSS REFERENCE TO RELATED APPLICATIONS (1) This application is a national stage filing under 35 U.S.C. 371 of PCT/IB2021/053748, filed May 4, 2021, which claims the benefit of U.S. Provisional Application No. 63/033,313, filed Jun. 2, 2020, the disclosures of which are incorporated by reference in their entireties herein.

TECHNICAL FIELD
(1) The present disclosure relates to a contactor system. More particularly, the present disclosure relates to the contactor system and a method of operating the contactor system.
BACKGROUND
(2) A contactor is typically used to treat a fluid for varying a mass content and/or a heat content of the fluid. Accordingly, the contactor may be used in an evaporative cooling system, a heating system, a humidifying system, a dehumidifying system, and the like. The contactor may be used to bring two immiscible fluid phases (such as gas/gas, liquid/liquid, gas/liquid) in contact with each other to cause mass transfer and/or heat transfer from one fluid to another.
(3) Such contactors typically include a contactor media installed in a frame member. Conventional contactors either include a wetted cellulosic media or a membrane array such as that explained in U.S. Pat. No. 9,541,302, hereinafter referred to as the '302 patent. The '302 patent describes use of a flat panel contactor having a plurality of hollow fibers that realize the function of separation and/or transfer from one fluid to another. Further, the wetted cellulosic media are generally fragile and are difficult to clean/maintain. Moreover, the wetted cellulosic medias are susceptible to fouling due to bacteria and/or also prone to scaling. Additionally, dissolved minerals in the fluid that flows through the wetted cellulosic media may cause degradation of the wetted cellulosic media if the wetted cellulosic media is not in a constant dry state or a constant wet state.
(4) In large scale applications, usage of a single large contactor may not be feasible due to space constraints and/or servicing or replacement issues. Thus, a plurality of contactors may replace the single large contactor to realize requirements of large scale applications. Moreover, some applications may demand installation of the contactors in a compact space. Such applications may require the contactors to be arranged in a complex arrangement based on an availability of space in order to achieve a desired contactor efficiency. There may be instances where working with multiple contactors may involve longer time periods for mass and/or heat transfer, efficiency constraints, and other implementation challenges, particularly for applications involving a complex arrangement of the contactors. Thus, it is desirable to configure the contactors in a manner that may provide improved efficiency and involves a simpler arrangement of the contactors.
(5) Moreover, in some applications, one or more characteristics, such as temperature or humidity, of the fluid being released by the contactors may need to be controlled based on application requirements. However, such a control strategy may not be effective for wetted cellulosic type contactor medias as it may be challenging to control variables, such as a working fluid flow rate, for controlling the temperature or the humidity. Moreover, in some applications, such wetted cellulosic type contactor medias may require large amounts of the working fluid, such as water, for operating purposes which may increase a usage of the working fluid.
(6) Further, in large scale applications, such as in applications related to cooling of electronic components, thermal management control may be compromised due to presence of localized hot spots that are characterized by high temperature. Such hot spots may lead to non-uniform temperature/humidity within a room/area. Further, a lack of low temperature air at the hot spots

may cause recirculation of warm air which may in turn increase the temperature at the hotspots. In such applications, a temperature of the fluid, such as air, being released by the contactors may need to be reduced to promote efficient and uniform cooling. Thus, there is a need for an economical and improved solution to control the contactors and also increase a coefficient of performance of such contactors.

BRIEF SUMMARY

(7) Some embodiments of the present disclosure relates to a contactor system. The contactor system includes a plurality of contactor panels. Each contactor panel includes a frame member. Further, each contactor panel includes a membrane array adapted to be received within the frame member. The membrane array defines a first end portion and a second end portion. The membrane array includes a plurality of hollow fibers. The contactor system also includes a first manifold in selective fluid communication with the first end portion of the membrane array of each contactor panel, the first manifold being adapted to direct a first fluid towards the membrane array of each contactor panel. The contactor system further includes a second manifold in direct fluid communication with the second end portion of the membrane array of each contactor panel, the second manifold being adapted to receive the first fluid from the membrane array of each contactor panel. The contactor system includes a controller configured to provide selective fluid communication between the first manifold and the first end portion of the membrane array of each contactor panel.

(8) Some embodiments of the present disclosure relates to a contactor system. The contactor system includes a plurality of contactor panels. Each contactor panel includes a frame member. Each contactor panel also includes a membrane array adapted to be received within the frame member. The membrane array defines a first end portion and a second end portion. The membrane array includes a plurality of hollow fibers. Each contactor panel further includes a valve assembly in fluid communication with the first end portion of the membrane array. The contactor system also includes a first manifold in selective fluid communication with the first end portion of the membrane array of each contactor panel, the first manifold being adapted to direct a first fluid towards the membrane array of each contactor panel based on an operation of the valve assembly. The contactor system further includes a second manifold in direct fluid communication with the second end portion of the membrane array of each contactor panel, the second manifold being adapted to receive the first fluid from the membrane array of each contactor panel. The contactor system includes a controller communicably coupled with the valve assembly of each contactor panel. The controller is configured to selectively control the valve assembly of at least one contactor panel for providing selective fluid communication between the first manifold and the first end portion of the membrane array of the least one contactor panel.

(9) Some embodiments of the present disclosure relates to a method of operating a contactor system. The method includes introducing a first fluid within a first manifold of the contactor system. The contactor system further includes a second manifold, a plurality of contactor panels, and a controller, and wherein each contactor panel includes a membrane array and a valve assembly. The method also includes controlling, by the controller, the valve assembly associated with at least one contactor panel for providing selective fluid communication between the first manifold and the membrane array of the at least one contactor panel. The method further includes introducing the first fluid within the membrane array of the at least one contactor panel based on control of the valve assembly associated with the at least one contactor panel. The method includes controlling at least one characteristic of a second fluid flowing over the membrane array of the at least one contactor panel based on at least one of a mass transfer and a heat transfer between the first fluid flowing through the membrane array of the at least one contactor panel and the second fluid flowing over the membrane array of the at least one contactor panel

Description

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

(1) Like symbols in the drawings indicate like elements. To easily identify the discussion of any particular element or act, the most significant digit or digits in a reference number may refer to the figure number in which that element is first introduced.

(2) FIG. **1** illustrates a schematic view of a first contactor system in accordance with some embodiments discussed herein.

(3) FIG. **2**A illustrates a perspective view of an exemplary hollow fiber contactor panel associated with the first contactor system in accordance with some embodiments discussed herein.

(4) FIG. **2**B illustrates a schematic view of a membrane array of the contactor panel of FIG. **1** in accordance with some embodiments discussed herein.

(5) FIG. **2**C illustrates a schematic view of the membrane array of the contactor panel of FIG. **1** in accordance with some embodiments discussed herein.

(6) FIG. **3**A illustrates a first technique of knitting a plurality of hollow fibers associated with the membrane array of FIG. **2**B in accordance with some embodiments discussed herein.

(7) FIG. **3**B illustrates a second technique of knitting the plurality of hollow fibers associated with the membrane array of FIG. **2**B in accordance with some embodiments discussed herein.

(8) FIG. **4** is a schematic view illustrating a number of membrane arrays and a number of separator structures in accordance with some embodiments discussed herein.

(9) FIG. **5** illustrates an exemplary flat sheet membrane contactor panel in accordance with some embodiments discussed herein.

(10) FIG. **6**A illustrates a schematic view of a second contactor system including a chilling module in accordance with some embodiments discussed herein.

(11) FIG. **6**B illustrates an exemplary plot in accordance with some embodiments discussed herein.

(12) FIG. **7** illustrates a schematic view of a third contactor system including an evaporative contactor system having a chilling module and a dehumidification system having a regeneration module in accordance with some embodiments discussed herein.

(13) FIG. **8** illustrates a fourth contactor system including a contactor panel array having a number of contactor panels in accordance with some embodiments discussed herein.

(14) FIG. **9** illustrates a fifth contactor system including a number of contactor panel arrays in accordance with some embodiments discussed herein.

(15) FIGS. **10**A and **10**B illustrate a housing member and a contactor panel being received within the housing member in accordance with some embodiments discussed herein.

(16) FIGS. **10**C and **10**D illustrate the contactor panel installed in different orientations in accordance with some embodiments of the present disclosure herein

(17) FIG. **11** illustrates a room equipped with contactor panels in accordance with some embodiments discussed herein.

(18) FIG. **12** illustrates another embodiment of a contactor system in accordance with some embodiments discussed herein.

(19) FIG. **13** illustrates a schematic representation of an exemplary test set-up having a contactor panel in accordance with some embodiments discussed herein.

(20) FIG. **14** illustrates a first exemplary plot in accordance with some embodiments discussed herein.

(21) FIG. **15** is a flowchart for a method of controlling the contactor panel.

DETAILED DESCRIPTION

(22) In the following description, reference is made to the accompanying figures that form a part thereof and in which various embodiments are shown by way of illustration. It is to be understood that other embodiments are contemplated and may be made without departing from the scope or

spirit of the present disclosure. The following detailed description, therefore, is not to be taken in a limiting sense.
(23) In the context of present disclosure, the terms “first” and “second” are used as identifiers. Therefore, such terms should not be construed as limiting of this disclosure. The terms “first” and “second” when used in conjunction with a feature or an element can be interchanged throughout the embodiments of this disclosure.
(24) The present disclosure generally relates to contactor systems and method of operating such contactor systems. In various embodiments, the contactor system may include a combination of different contactor assemblies. Such contactor assemblies may include one or more contactor panels that are used for mass transfer and/or heat transfer in an air handling, ventilation, or duct system. The contactor panels include a membrane array having a number of hollow fibers. A first fluid flows through the hollow fibers while a second fluid contacts an outer surface of the hollow fibers. Further, the present disclosure describes contactor systems having a plurality of contactor panels that may be individually controlled to vary one or more characteristics, such as temperature and/or humidity, of the second fluid. A controller may be used to vary the characteristics of the second fluid based on presence of a potential hot spot in a room, such as a data center, a target temperature, a target humidity, and/or a temperature uniformity metric.
(25) Moreover, such contactor systems may include one or more contactor panel arrays. Each contactor panel array includes an inlet manifold and an outlet manifold associated therewith. Further, the contactor system may be used for cooling electronic components, such as servers, installed in a room. Accordingly, one or more contactor panels may be installed in a floor, an aisle, or a wall of the room towards which treated air needs to be directed. Further, various embodiments of the contactor system described in this disclosure may be associated with an air duct, ventilation air duct, return (return air grille), vent, diffuser, filter housing, air handling equipment. The air handling equipment may include a Heating, Ventilation, and Air conditioning (HVAC) equipment, Heating, Ventilation, Air conditioning, and Refrigeration (HVACR or HVAC&R) equipment, Heating, Air conditioning, and Refrigeration (HACR) equipment, forced ventilation equipment, Energy Recovery Ventilation (ERV) equipment, Air conditioning (AC) equipment, refrigeration equipment, air handlers, and the like.
(26) FIG. **1** illustrates a schematic view of a first contactor system **100**, according to an embodiment of the present disclosure. The first contactor system **100** may include at least one of an evaporative cooling system, a dehumidification system, and a combination thereof. As illustrated herein, the first contactor system **100** is a combination of a dehumidification system **102** and an evaporative cooling system **104**. In the illustrated embodiment, the dehumidification system **102** is embodied as a closed loop system having a first contactor panel **112**. Further, an operation of the dehumidification system **102** is independent of an orientation of the first contactor panel **112** as a first fluid flowing through the first contactor panel **112** does not drip by gravity. More particularly, the dehumidification system **102** includes components that direct the first fluid towards the contactor panel **112** and may not require positioning of a reservoir/distributor at an elevation. The first contactor system **100** includes a first tank **106**. The first tank **106** is embodied as a reservoir or vessel for holding the first fluid therein. In some examples, the first fluid may be precooled or preheated based on an application of the dehumidification system **102**. Accordingly, the first tank **106** may be in fluid communication with a chilling module (similar to a chilling module **640** that will be explained later in this section) or a heating module (not shown) in order to precool or preheat the first fluid. In one example, the first fluid is at least one of a liquid and a gas. Further, the first fluid may include a liquid, a gas, a sweep gas, air, forced air, a vacuum, or combinations thereof. The liquid may include, for example, a cold and/or absorbent liquid, a salt solution, a hot and/or humidifying liquid, or a liquid desiccant. A type of the first fluid may vary based on an application of the first contactor system **100**. In the illustrated example, the first fluid is the liquid desiccant. In another example, the first fluid may be hot and humid air.

(27) The first contactor system **100** also includes a first pump **108**. The first pump **108** is disposed in a first fluid conduit **110** that provides fluid communication between the first tank **106** and a first contactor panel **112**. The first pump **108** pressurizes the first fluid to introduce the pressurized first fluid in the first contactor panel **112**. In some examples, the first pump **108** may be designed to pressurize the first fluid to a pressure not higher than 5 pounds per square inch. The first pump **108** may further allow variation in a flow rate of the first fluid being directed towards the first contactor panel **112**. The flow rate of the first fluid may vary based on a size of the contactor system **100** or an application thereof. In some examples, the flow rate may be approximately equal to 0.5 Gallon Per Minute (GPM) to 1 GPM. In other examples, the first fluid may flow at higher flow rates based on a type of application. In other embodiments, the dehumidification system **102** may be designed such that the first fluid drips through the first contactor panel **112** by gravity, without limiting the scope of the present disclosure.
(28) Further, the first contactor system **100** includes a first blower unit **114** associated with the first contactor system **100**. The first blower unit **114** directs a second fluid towards the first contactor panel **112**. The first blower unit **114** may allow the second fluid to be pushed or pulled through the first contactor panel **112**. In one example, the second fluid is at least one of a liquid and a gas. The second fluid may include a liquid, a gas, sweep gas, air, forced air, a vacuum, or combinations thereof. The liquid may include, for example, a cold and/or absorbent liquid, a salt solution, a hot and/or humidifying liquid, or a liquid desiccant. A type of the second fluid may vary based on an application of the first contactor system **100**. Further, in the illustrated example, the second fluid is hot and humid air. In another example, the second fluid may be the liquid desiccant. In some examples, a filter **406** (shown in FIG. **4**) is positioned upstream of the first contactor panel **112** to allow filtering of the second fluid before the second fluid contacts a membrane array **132** of the first contactor panel **112**.
(29) Referring to FIG. **2**A, the first contactor panel **112** includes a frame member **116**. The frame member **116** may be square or rectangular in shape. The frame member **116** defines a first side panel **118** and a second side panel **120**. The frame member **116** of the first contactor panel **112** defines a first headspace **122** in fluid communication with the first tank **106** (see FIG. **2**) via the first fluid conduit **110** (see FIG. **1**). The first headspace **122** defines a first port **124** that projects outwards from the first headspace **122**. The first tank **106** is in fluid communication with the first headspace **122** via the first port **124**. Further, the first headspace **122** is generally cuboid shaped. The frame member **116** also defines a second headspace **126** in fluid communication with the first tank **106** via a second fluid conduit **128** (shown in FIG. **1**). The second headspace **126** defines a second port **130** that projects outwards from the second headspace **126**. The first tank **106** is in fluid communication with the second headspace **126** via the second port **130**. Further, the second headspace **126** is generally cuboid shaped. The first side panel **118**, the second side panel **120**, the first headspace **122**, and the second headspace **126** may be joined, glued, or welded to each other.
(30) The first contactor panel **112** includes the membrane array **132** adapted to be received within the frame member **116**. The membrane array **132** defines a first end portion **134** (shown in FIG. **1**) and a second end portion **136** (shown in FIG. **1**). The membrane array **132** includes at least one of a plurality of hollow fibers **138**, a flat sheet membrane, and a combination thereof. In some examples, each hollow fiber **138** includes a capillary membrane. In yet other examples, the membrane array **132** may include a ceramic membrane array.
(31) In the illustrated example, the contactor panel **112** is embodied as a hollow fiber membrane contactor panel. Accordingly, the membrane array **132** includes the plurality of hollow fibers **138**. The membrane array **132** extends between the first headspace **122** and the second headspace **126**. In the illustrated example, the membrane array **132** is embodied as a dehumidification media. Further, the membrane array **132** is similar to the hollow fiber membrane array described in U.S. Pat. No. 9,541,302, hereinafter referred to as '302 patent. It should be noted that details corresponding to a design, material, and manufacturing of the membrane array **132** is similar to a

design, material, and manufacturing of the hollow fiber membrane array described in the '302 patent.

(32) Referring to FIG. **2**B, a portion of the membrane array **132** is illustrated. The membrane array **132** includes the plurality of hollow fibers **138** extending along a first fiber axis “A-A**1**”. Further, each hollow fiber **138** includes a lumen **140** adapted to receive the first fluid. The lumen **140** may be hereinafter interchangeably referred to as a first portion **140**. A flow of the first fluid through the first contactor system **100** is illustrated by a first fluid flow “F**1**” (shown in FIG. **1**). Moreover, each hollow fiber **138** includes an exterior surface **142** adapted to contact the second fluid. The exterior surface **142** may be hereinafter interchangeably referred to as a second portion **142**. A flow of the second fluid through the first contactor system **100** is illustrated by a second fluid flow “F**2**” (shown in FIG. **1**). A wall **144** of each hollow fiber **138** separates the lumen **140** and the exterior surface **142**. Each hollow fiber **138** defines a first end **146** and a second end **147** that are embodied as open ends.

(33) Further, in order to couple the membrane array **132** with the first and second headspaces **122**, **126** (see FIG. **2**A), the first and second ends **146**, **147** of each hollow fiber **138** are potted sealed around an outer diameter of the hollow fiber **138** using a potting material. The ends **146**, **147** may be embedded in a resin by potting methods, such as gravity potting method, mold potting method, centrifugal potting method, and the like. The potting material may include epoxy, thermoplastics, polyurethane, etc. The potting material may seal each hollow fiber **138** to the first headspace **122** and the second headspace **126**. It should be noted that the ends **146**, **147** are potted sealed such that each lumen **140** is in fluid communication with the first headspace **122** and the second headspace **126**, respectively.

(34) Further, the membrane array **132** of the first contactor panel **112** (see FIG. **2**A) is a microporous, hydrophobic, hollow fiber membrane array. Because of the hydrophobic nature of the membrane array **132**, the membrane array **132** acts as an inert support to allow direct contact between a gas phase and a liquid phase, without dispersion. Further, a material of the membrane array **132** creates a barrier between the first fluid and the second fluid. The membrane array **132** may be manufactured using a dry stretch process. The membrane array **132** may be made of one or more of a polymer such as a polyolefin (PO), a polypropylene (PP), a polymethyl pentene (PMP, or poly(4-methyl-1-pentene)), and the like.

(35) Further, pore sizes of the hollow fibers **138** of the membrane array **132** may be between 0.01 micron and 0.05 micron. In a specific example, the pore sizes of the hollow fibers **138** may be less than 0.04 micron. Thus, such as legionella, and/or dissolved minerals may be prevented from entering the second fluid, which may reduce a probability of surface fouling occurrence and scale buildup. Moreover, a turbulent flow nature of the second fluid through the hollow fibers **138** may also reduce the surface fouling occurrence. As the pores may block bacteria and/or other dissolved minerals from entering the second fluid, the contactor panel may be used for filtering liquids, de-bubbling liquids, and the like. Further, reduction in fouling occurrence and scale buildup in the membrane array **132** may reduce maintenance cost, a need for frequent cleaning of the first contactor panel **112**, reduction in power consumption, and improvement in an efficiency of the first contactor panel **112**. Moreover, the membrane array **132** associated with the first contactor panel **112** may be easily cleaned by an acid rinse through the hollow fibers **138**. This technique may provide an easy and effective way of cleaning the membrane array **132**. Additionally, the membrane array **132** may work reliably, may prolong product overhaul period, and may also allow reduction in a downtime and maintenance time associated with the first contactor system **100**.

(36) FIG. **2**C illustrates a magnified view of the membrane array **132**. It should be noted that an arrangement of the membrane array **132** illustrated herein is exemplary in nature. The membrane array **132** of the first contactor panel **112** (see FIG. **2**A) includes at least one membrane layer **148**. The at least one membrane layer **148** includes the plurality of hollow fibers **138**. In the illustrated embodiment, the membrane array **132** includes a plurality of membrane layers **148** disposed

adjacent to each other. The membrane layers **148** may be folded, pleated, or wound along a depth "D**1**" to form the membrane array **132**. For example, the membrane layers **148** may be folded, pleated, wound, or bundled together such that the number of membrane layers **148** are disposed adjacent to each other. In the illustrated embodiment, the membrane array **132** includes sixty membrane layers **148**, without any limitations. In another embodiment, the membrane array **132** may include twenty membrane layers or forty membrane layers, as per application requirements. Further, each membrane layer **148** includes eight hollow fibers **138**. It may be contemplated that a total number of the membrane layers **148** and a total number of the hollow fibers **138** may vary, as per application requirements. The number of membrane layers **148** and the hollow fibers **138** may depend upon a desired efficiency of the first contactor panel **112**. It should be noted that, in some examples, the efficiency of the first contactor panel **112** may be increased by increasing the membrane layers **148** and the hollow fibers **138**.

(37) Further, the plurality of hollow fibers **138** are knitted to form the membrane array **132**. In one example, as illustrated in FIG. **3**A, the hollow fibers **138** may be knitted using a number of straight threads **302** to form the membrane array **132**. More particularly, a straight knit mat technology may be used to knit the hollow fibers **138**. In another example, as illustrated in FIG. **3**B, the hollow fibers **138** are knitted by cross threads **304** to form the membrane array **132**. More particularly, a cross wound mat technology may be used to knit the membrane array **132**. Further, in some examples, the membrane array **132** may be skewed together. The threads **302**, **304** may be made of a material that is similar to a material of the hollow fibers **138**. In one example, the threads **302**, **304** may be made of PP. A material of the threads **302**, **304** may be decided such that the threads **302**, **304** are compatible with the second fluid.

(38) FIG. **4** illustrates another embodiment of the present disclosure. The contactor panel **400** includes at least two membrane arrays **402** disposed adjacent to each other. In the illustrated example, the contactor panel **400** includes five membrane arrays **402** disposed adjacent to each other. However, it should be noted that a total number of the membrane arrays **402** may vary as per application requirements. Each membrane array **402** is similar to the membrane array **132** described in relation to FIGS. **2**A to **2**C. Further, the contactor panel **400** includes at least one separator structure **404** disposed adjacent to the membrane array **402**. In the illustrated embodiment, the contactor panel **400** includes four separator structures **404**, such that a separator structure **404** is disposed between adjacently disposed membrane arrays **402**. Further, the separator structures **404** may have same thicknesses or each separator structure **404** may have varying thickness.

(39) A shape and a dimension of the separator structures **404** corresponds to a shape and a dimension of the membrane arrays **402** so that the separator structures **404** can be received between the adjacent membrane arrays **402**. In one example, the separator structure **404** is manufactured from a non-woven material. In some examples, the separator structure **404** may be manufactured from a metal or a plastic that is compatible with the second fluid flowing across the contactor panel **400**. The separator structure **404** may include various designs. For example, the separator structure **404** may include a grille structure including a number of horizontally and/or vertically arranged bar members, a honeycomb structure, a sheet of metal or polymer having a number of through apertures, and the like, without any limitations.

(40) The separator structure **404** may provide support to the membrane arrays **402** and may prevent the membrane arrays **402** from flexing, unfolding, unwinding, or spreading. The separator structure **404** decreases deflection of hollow fibers of the membrane arrays **402** and provides structural stability to the membrane arrays **402** against pressure being applied by the second fluid. Moreover, incorporation of the separator structure **404** may increase an overall thickness of the contactor panel **400**. The increase in the thickness of the contactor panel **400** may increase an exposure time of the second fluid flowing across the contactor panel **400** and may cause reduction in pressure drop across the contactor panel **400**. Such a phenomenon may in turn improve effectiveness of the

contactor panel **400**. Further, the filter **406** is disposed proximate to the contactor panel **400**, and more particularly, at an inlet side of the contactor panel **400** so that the flow "F**2**" of the second fluid may be filtered before the second fluid contacts the membrane arrays **402**.

(41) Although the present disclosure is being described in relation to the contactor panel **112** (see FIG. **1**) having the hollow fibers **138** (see FIG. **2**B), the teachings of the present disclosure can be implemented to other types of contactor panels including, but not limited to, flat sheet membrane contactor panels, capillary membrane contactor panels, and/or ceramic membrane contactor panels, without any limitations. Such flat sheet membrane contactor panels or capillary membrane contactor panels may be used when the contactor system **100** (see FIG. **1**) is embodied as an air desiccation system.

(42) Referring to FIG. **5**, an exemplary flat sheet membrane contactor panel **500** is illustrated. The schematically illustrated flat sheet membrane contactor panel **500** may provide heat and/or mass transfer between the first fluid and the second fluid. The flat sheet membrane contactor panel **500** may include a number of flat sheet membrane arrays **502** disposed adjacent to each other, such that channels **504**, **506** exist therebetween. The channels **504** may receive the second fluid whereas the channels **506** may receive the first fluid. In other examples, the contactor panel **500** may be embodied as a spiral wound contactor panel, without any limitations. Further, the flat sheet membrane arrays **502** may be made of one or more of a polymer such as PO, PP, PMP, and the like. In some alternative embodiments, the flat sheet membrane contactor panel **500** may include, but not limited to, parallel-plate membrane contactor panels. In some of these alternative embodiments, the contactor panel **500** may include, but not limited to, cross-flow parallel-plate membrane contactor panels, counter-flow parallel-plate membrane contactor panels, quasi-counter-flow flow parallel-plate membrane contactor panels, or any combination thereof.

(43) Referring now to FIG. **1**, during an operation of the dehumidification system **102**, the first headspace **122** receives the first fluid from the first tank **106** via the first fluid conduit **110** and the first port **124**. The first headspace **122** directs the first fluid, such as the liquid desiccant, through the lumen **140** (see FIG. **2**B) of each hollow fiber **138**. The first fluid flows through the lumen **140** of each hollow fiber **138** and is introduced in the second headspace **126**. The second headspace **126** in turn directs the first fluid towards the first tank **106** via the second port **130** and the second fluid conduit **128**. Further, the first blower unit **114** directs the second fluid, such as air, towards the exterior surface **142** (see FIG. **2**B) of each hollow fiber **138**. Based on the flow of the second fluid over the membrane array **132**, a humidity of the second fluid decreases based on mass transfer between the first fluid and the second fluid. The second fluid that is released may be hot and dry air. Further, only mass transfer occurs when the first contactor panel **112** is used in the dehumidification system **102**. Moreover, the mass transfer between the liquid and gas phases is governed entirely by a pressure of the gas phase.

(44) It should be noted that the first fluid may not pass through the pores of the hollow fibers **138**. Due to the micro pore size of the hollow fibers **138**, the first fluid permeating towards the exterior surface **142** of the hollow fibers **138** is converted to water mist, which may further improve an evaporation rate. The wall **144** (see FIG. **2**B) of each hollow fiber **138** may act as an inert medium that may bring the first fluid and the second fluid into direct contact, without dispersion. It should be noted that the first contactor panel **112** described herein may provide a high contact surface area to volume ratio which may in turn translate to a compact footprint and system size and may also improve an efficiency of the contactor system.

(45) Further, the first contactor system **100** includes the evaporative cooling system **104**. The first contactor system **100** includes a second tank **150**. The second tank **150** is embodied as a reservoir or vessel for holding a third fluid therein. In one example, the third fluid is at least one of a liquid and a gas. Further, the third fluid may include a liquid, a gas, a sweep gas, air, forced air, a vacuum, or combinations thereof. The liquid may include, for example, a cold and/or absorbent liquid, a salt solution, a hot and/or humidifying liquid, or a liquid desiccant. A type of the third fluid may vary

based on an application of the first contactor system **100**. In the illustrated example, the third fluid is water. In another examples, the third fluid may be hot and dry air.

(46) The first contactor system **100** also includes a second pump **152**. The second pump **152** is disposed in a third fluid conduit **154** that provides fluid communication between the second tank **150** and a second contactor panel **156**. The second pump **152** pressurizes the third fluid to introduce the pressurized third fluid in the second contactor panel **156**. Further, the first contactor system **100** includes a second blower unit **158**. The second blower unit **158** directs a fourth fluid towards the second contactor panel **156**. In one example, the fourth fluid is at least one of a liquid and a gas. The fourth fluid may include a liquid, a gas, sweep gas, air, forced air, a vacuum, or combinations thereof. The liquid may include, for example, a cold and/or absorbent liquid, a salt solution, a hot and/or humidifying liquid, or a liquid desiccant. A type of the fourth fluid may vary based on an application of the first contactor system **100**. Further, in the illustrated example, the fourth fluid is a portion of the dry and hot air that is released by the dehumidification system **102**. In another example, the fourth fluid may be water.

(47) The second contactor panel **156** includes a frame member **157**. The frame member **157** may be square or rectangular in shape. The frame member **157** defines a first side panel (not shown) and a second side panel (not shown). The frame member **157** of the second contactor panel **156** defines a first headspace **162** in fluid communication with the second tank **150** via the third fluid conduit **154**. The first headspace **162** defines a first port **164** that projects outwards from the first headspace **162**. The second tank **150** is in fluid communication with the first headspace **162** via the first port **164**. Further, the first headspace **162** is generally cuboid shaped. The frame member **157** also defines a second headspace **166** in fluid communication with the second tank **150** via a fourth fluid conduit **151**. The second headspace **166** defines a second port **168** that projects outwards from the second headspace **166**. The second tank **150** is in fluid communication with the second headspace **166** via the second port **168**. The second headspace **166** is generally cuboid shaped. The first side panel, the second side panel, the first headspace **162**, and the second headspace **166** may be joined, glued, or welded to each other.

(48) The second contactor panel **156** includes a membrane array **170** adapted to be received within the frame member **157**. The membrane array **170** defines a first end portion **172** and a second end portion **174**. The membrane array **170** includes a plurality of hollow fibers **176**. The membrane array **170** extends between the first headspace **162** and the second headspace **166**. In the illustrated example, the membrane array **170** is embodied as an evaporative cooling media. The membrane array **170** is similar in construction, design, and material to the membrane array **132** explained in relation to the first contactor panel **112**. Further, each hollow fiber **176** includes a lumen (not shown) adapted to receive the third fluid. Moreover, each hollow fiber **176** includes an exterior surface (not shown) adapted to contact the fourth fluid. A wall (not shown) of each hollow fiber **176** separates the lumen and the exterior surface. Each hollow fiber **176** defines a first end (not shown) and a second end (not shown) that are embodied as open ends.

(49) During an operation of the evaporative cooling system **104**, the first headspace **162** receives the third fluid from the second tank **150**. The first headspace **162** directs the third fluid, such as water, through the lumen of each hollow fiber **176**. A flow of the third fluid through the first contactor system **100** is illustrated by a third fluid flow “F**3**”. The third fluid flows through the lumen of each hollow fiber **176** and is introduced in the second headspace **166**. The second headspace **166** in turn directs the third fluid towards the second tank **150**. Further, the second blower unit **158** directs the fourth fluid, such as dry and hot air, towards the exterior surface of each hollow fiber **176**. A flow of the fourth fluid through the first contactor system **100** is illustrated by a fourth fluid flow “F**4**”. Based on the flow of the fourth fluid over the membrane array **170**, a temperature and a humidity of the fourth fluid decreases based on heat and mass transfer between the third fluid and the fourth fluid. Further, the fourth fluid that is released may be cool and humid air. Moreover, both heat transfer and mass transfer occur when the second contactor panel **156** is

used in the evaporative cooling system **104**. It should be noted that the mass transfer between the liquid and gas phases is governed by a pressure of the gas phase. It should be noted that the third fluid may not pass through the pores of the hollow fibers **176**. Only water vapor may pass from the lumen towards the exterior surface through evaporation. The wall of each hollow fiber **176** may act as an inert medium that may bring the third fluid and the fourth fluid into direct contact, without dispersion. Further, as only water vapor passes across the membrane, requirement of a mist capturing screen in a duct may be eliminated.

(50) FIG. **6**A illustrates a second contactor system **600**, according to an embodiment of the present disclosure. The second contactor system **600** includes an evaporative cooling system **604**. The evaporative cooling system **604** is similar in design to the dehumidification system **102** associated with the first contactor system **100** explained in relation to FIG. **1**. Accordingly, the second contactor system **600** includes a tank **606**, a pump **608**, a blower unit **614**, a first fluid conduit **610**, a second fluid conduit **628**, and a contactor panel **612** that is similar to the first tank **106**, the first pump **108**, the first blower unit **114**, the first fluid conduit **110**, the second fluid conduit **128**, and the first contactor panel **112**. The pump **608** pressurizes the first fluid to introduce the pressurized first fluid in the contactor panel **612**. In the illustrated example, the first fluid is water. In another example, the first fluid may be dry and hot air. Further, the blower unit **614** directs a second fluid towards the contactor panel **612**. In the illustrated example, the second fluid is dry and hot air. In another example, the second fluid may be water.

(51) The contactor panel **612** includes a first headspace **622**, a second headspace **626**, a membrane array **632**, and a plurality of hollow fibers **638** similar to the first headspace **122**, the second headspace **126**, the membrane array **132**, and the plurality of hollow fibers **138**. During an operation of the evaporative cooling system **604**, the first headspace **622** receives the first fluid from the tank **606**. The first headspace **622** directs the first fluid, such as water, through a lumen (not shown) of each hollow fiber **638**. A flow of the first fluid through the second contactor system **600** is illustrated by a first fluid flow “F**1**”. The first fluid flows through the lumen of each hollow fiber **638** and is introduced in the second headspace **626**. Further, the blower unit **614** directs the second fluid, such as dry and hot air, towards an exterior surface (not shown) of each hollow fiber **638**. A flow of the second fluid through the second contactor system **600** is illustrated by a second fluid flow “F**2**”. Based on the flow of the second fluid over the membrane array **632**, a temperature and a humidity of the second fluid decreases based on heat transfer and mass transfer between the first fluid and the second fluid. Thus, both heat transfer and mass transfer occur when the contactor panel **612** is used in the evaporative cooling system **604**.

(52) Moreover, the second headspace **626** directs the first fluid towards the tank **606** via the second fluid conduit **628**. Further, the second contactor system **600** includes the chilling module **640** fluidly coupled with the tank **606**. The chilling module **640** is adapted to decrease a temperature of the first fluid. The chilling module **640** may increase a cooling efficiency of the second contactor system **600**. The chilling module **640** includes a coolant reservoir **646**. The coolant reservoir **646** holds a coolant, such as chilled water, therein. The chilling module **640** also includes a heat exchanger **642** in fluid communication with the coolant reservoir **646** and the tank **606**. The heat exchanger **642** includes a number of tubes **644**. The heat exchanger **642** is in fluid communication with the coolant reservoir **646** via a first fluid pipe **648**. The coolant received from the coolant reservoir **646** flows through the tubes **644**.

(53) Further, a coolant pump **650** is fluidly disposed between the tank **606** and the heat exchanger **642**. The coolant pump **650** is disposed in the first fluid pipe **648**. The coolant pump **650** is adapted to pressurize the coolant being directed towards the heat exchanger **642**. Further, the fluid exiting the heat exchanger **642** is directed towards the coolant reservoir **646** via a second fluid pipe **652**. The heat exchanger **642** also includes a third fluid pipe **654** that is in fluid communication with the second fluid conduit **628**. The third fluid pipe **654** receives the first fluid exiting the contactor panel **612**. A second pump **658** is disposed in the third fluid pipe **654** to pressurize and deliver the first

fluid towards the heat exchanger **642**. Further, the first fluid received within the heat exchanger **642** is adapted to flow over the tubes **644**. As the first fluid flows over the tubes **644**, the temperature of the first fluid decreases due to heat exchange between the coolant and the first fluid. Further, a fourth fluid pipe **656** provides fluid communication between the heat exchanger **642** and the tank **606**. The fourth fluid pipe **656** directs the first fluid that is at a lower temperature towards the tank **606** from where the first fluid may be directed towards the contactor panel **612**.
(54) Further, incorporation of the chilling module **640** provides an additional heat exchange mechanism to lower the temperature of the first fluid, such as water, being directed towards the contactor panel **612**. Such a technique may allow the contactor system **600** to achieve improved saturation effectiveness over conventional contactor systems. More particularly, at elevated temperature and humidity levels, the contactor panel **612** may allow latent heat transfer thereby allowing water evaporation and cooling of the second fluid. Further, once a relative humidity at each pore site approaches 100%, water evaporation slows down. In such instances, lowering the temperature of the first fluid using the chilling module **640** may also allow sensible heat transfer as the temperature of the first fluid is lower than that of the second fluid. This additional heat exchange mechanism may further allow cooling of the second fluid and warming of the first fluid.
(55) Table 1 provided below illustrates findings based on a first experiment and a second experiment performed on a contactor panel similar to the contactor panel **112** (shown in FIG. **1**) or the contactor panel **612**. The contactor panel included a 20 layered membrane array. All temperatures were measured in Fahrenheit (° F.).
(56) TABLE-US-00001 TABLE 1 Inlet Air Outlet Air Inlet Water Outlet Water Room Serial Temperature Temperature Temperature Temperature Temperature Saturation Number (° F.) (° F.) (° F.) (° F.) (° F.) Effectiveness First 72 64.6 67.8 65.2 72.5 40.8 Experiment Second 101.3 77.4 73.2 86.6 74.0 127.3 Experiment
(57) As illustrated in Table 1, in the first experiment, inlet air temperature was approximately equal to room temperature. Further, in the first experiment, a low temperature difference existed between the inlet air temperature and inlet water temperature. From the first experiment it was concluded that due to the low temperature difference between the inlet air temperature and the inlet water temperature, outlet water temperature decreases and only latent heat transfer occurs between water and air. Further, in the second experiment, the inlet air temperature was approximately equal to 101° F. In the second experiment, a high temperature difference existed between the inlet air temperature and the inlet water temperature. From the second experiment it was concluded that due to the high temperature difference between the inlet air temperature and the inlet water temperature, the outlet water temperature increases and both latent heat transfer and sensible heat transfer occurs between water and air. It was further found that in the second experiment the saturation effectiveness may be more than 100% due to combination of latent heat transfer and sensible heat transfer between water and air.
(58) Table 2 provided below illustrates findings based on a third experiment and a fourth experiment performed on a contactor panel similar to the contactor panel **112**/**612**. The contactor panel included a 40 layered membrane array. All temperatures were measured in Fahrenheit (° F.).
(59) TABLE-US-00002 TABLE 2 Inlet Air Outlet Air Inlet Water Outlet Water Room Serial Temperature Temperature Temperature Temperature Temperature Saturation Number (° F.) (° F.) (° F.) (° F.) (° F.) Effectiveness Third 72 63 67.8 62.7 72.5 50 Experiment Fourth 97.3 70.2 67.8 81.2 71.8 143.5 Experiment
(60) As illustrated in Table 2, in the third experiment, inlet air temperature was approximately equal to room temperature. Further, in the third experiment, a low temperature difference existed between the inlet air temperature and inlet water temperature. From the third experiment it was concluded that due to the low difference between the inlet air temperature and the inlet water temperature, outlet water temperature decreases and only latent heat transfer occurs between water and air. Further, in the fourth experiment, the inlet air temperature was approximately equal to 97° F. In in

the fourth experiment, a high temperature difference existed between the inlet air temperature and the inlet water temperature. From the fourth experiment it was concluded that due to the high difference between the inlet air temperature and the inlet water temperature, the outlet water temperature increases and both latent heat transfer and sensible heat transfer occurs between water and air. It was further found that in the fourth experiment the saturation effectiveness may be more than 100% due to combination of latent heat transfer and sensible heat transfer between water and air.

(61) FIG. **6**B illustrates an exemplary plot **660**. Various values for velocity (in meters per second) of inlet air are marked on X-axis and various values for saturation effectiveness are marked on Y-axis. Further, the plot **660** illustrates a number of points **662**, **664**, **666**, **668** that represent data based on a series of experiments performed on contactor panels, similar to the contactor panel **112**, associated with the contactor system **100** of FIG. **1**, or the contactor panel **612**, associated with the contactor system **600** of FIG. **6**A. More particularly, the number of first points **662** were plotted based on a series of experiments performed on a contactor panel with a 40 layered membrane array at a water flow rate of approximately 1 GPM. Moreover, the number of second points **664** were plotted based on a series of experiments performed on a contactor panel with a 40 layered membrane array at a water flow rate of approximately 0.5 GPM. Further, the number of third points **666** were plotted based on a series of experiments performed on a contactor panel with a 20 layered membrane array at a water flow rate of approximately 1 GPM. Additionally, the number of fourth points **668** were plotted based on a series of experiments performed on a contactor panel with a 20 layered membrane array at a water flow rate of approximately 0.5 GPM.

(62) It should be noted that a temperature of the inlet air being directed towards the contactor panels for each experiment was approximately equal to 100° F. From the plot **660**, it can be concluded that the contactor panels may demonstrate higher saturation effectiveness if a difference between the temperature of the inlet air and a temperature of inlet water is greater. The reason for the high saturation effectiveness may be attributed to a combination of latent heat transfer and sensible heat transfer from water to the air due to higher temperature difference between the temperature of the inlet air and the temperature of the inlet water. It was further found that the saturation effectiveness may be more than 100% due to combination of latent heat transfer and sensible heat transfer from water to air.

(63) FIG. **7** illustrates a schematic view of a third contactor system **700**, according to an embodiment of the present disclosure. The third contactor system **700** includes a dehumidification system **702** and an evaporative cooling system **704**. The dehumidification system **702** is similar in design to the dehumidification system **102** of the first contactor system **100** of FIG. **1**. Further, the third contactor system **700** includes a first tank **706**, a first pump **708**, a first blower unit **714**, a first fluid conduit **710**, a second fluid conduit **728**, and a first contactor panel **712** that is similar to the first tank **106**, the first pump **108**, the first blower unit **114**, the first fluid conduit **110**, the second fluid conduit **128**, and the first contactor panel **112**. The first pump **708** pressurizes the first fluid to introduce the pressurized first fluid in the first contactor panel **712**. In the illustrated example, the first fluid is a liquid desiccant. In another example, the first fluid may be humid and hot air. Further, the first blower unit **714** directs a second fluid towards the first contactor panel **712**. In the illustrated example, the second fluid is humid and hot air. In another example, the second fluid may be water.

(64) Further, the first contactor panel **712** includes a first headspace **722**, a second headspace **726**, a membrane array **732**, and a plurality of hollow fibers **738** similar to the first headspace **122**, the second headspace **126**, the membrane array **132**, and the plurality of hollow fibers **138**. During an operation of the dehumidification system **702**, the first headspace **722** receives the first fluid from the first tank **706** via the first fluid conduit **710**. The first headspace **722** directs the first fluid, such as the liquid desiccant, through a lumen (not shown) of each hollow fiber **738**. A flow of the first fluid through the third contactor system **700** is illustrated by a first fluid flow “F**1**”. The first fluid

flows through the lumen of each hollow fiber **738** and is introduced in the second headspace **726**. Further, the first blower unit **714** directs the second fluid, such as the hot and humid air, towards an exterior surface (not shown) of each hollow fiber **738**. A flow of the second fluid through the third contactor system **700** is illustrated by a second fluid flow “F**2**”. Based on the flow of the second fluid over the membrane array **732**, a humidity of the second fluid decreases based on mass transfer between the first fluid and the second fluid. The second fluid that is released may be hot and dry air. The second headspace **726** in turn directs the first fluid towards the first tank **706** via the second fluid conduit **728**.

(65) Further, the third contactor system **700** includes a regeneration module **778** to increase a desiccant concentration of the liquid desiccant. The regeneration module **778** includes a first heat exchanger **779** having a number of tubes **780**. The first heat exchanger **779** is disposed in the second fluid conduit **728**. A second blower unit **781** directs the second fluid towards the first heat exchanger **779** such that the second fluid flows through the tubes **780** of the first heat exchanger **779**. The first heat exchanger **779** receives the first fluid from the first contactor panel **712**. Further, the first fluid flows over the tubes **780** of the first heat exchanger **779**. As the first fluid flows over the tubes **780**, the desiccant concentration of the liquid desiccant increases and the second fluid is converted to humid and hot air. The first fluid exiting the first heat exchanger **779** is directed towards the first tank **706** via the second fluid conduit **728**.

(66) Further, the evaporative cooling system **704** is similar in design to the dehumidification system **102** associated with the first contactor system **100** explained in reference to FIG. **1**. The third contactor system **700** includes a second tank **750**, a second pump **752**, a third blower unit **758**, a third fluid conduit **754**, a fourth fluid conduit **751**, and a second contactor panel **756** that is similar to the first tank **106**, the first pump **108**, the first blower unit **114**, the first fluid conduit **110**, the second fluid conduit **128**, and the first contactor panel **112**. The second pump **752** pressurizes a third fluid to introduce the pressurized third fluid in the second contactor panel **756**. In the illustrated example, the third fluid is water. In another example, the third fluid may be a portion of the dry and hot air being released by the dehumidification system **702**. Further, the third blower unit **758** directs a fourth fluid towards the second contactor panel **756**. In the illustrated example, the fourth fluid is a portion of the dry and hot air being released by the dehumidification system **702**. In another example, the fourth fluid may be water.

(67) Further, the second contactor panel **756** includes a first headspace **762**, a second headspace **766**, a membrane array **770**, and a plurality of hollow fibers **776** similar to the first headspace **122**, the second headspace **126**, the membrane array **132**, and the plurality of hollow fibers **138**. During an operation of the evaporative cooling system **704**, the first headspace **762** receives the third fluid from the second tank **750**. The first headspace **762** directs the third fluid, such as water, through a lumen (not shown) of each hollow fiber **776**. A flow of the third fluid through the third contactor system **700** is illustrated by a third fluid flow “F**3**”. The third fluid flows through the lumen of each hollow fiber **776** and is introduced in the second headspace **766**. Further, the third blower unit **758** directs the fourth fluid, such as hot and dry air, towards an exterior surface (not shown) of each hollow fiber **776**. A flow of the fourth fluid through the third contactor system **700** is illustrated by a fourth fluid flow “F**4**”. Based on the flow of the fourth fluid over the membrane array **770**, a temperature and a humidity of the fourth fluid decreases based on heat transfer and mass transfer between the third fluid and the fourth fluid.

(68) Further, the third contactor system **700** includes a chilling module **785** adapted to decrease a temperature of the third fluid. The chilling module **785** is similar to the chilling module **640** described in relation to the second contactor system **600** of FIG. **6**A. The chilling module **785** includes a second heat exchanger **786** having a number of tubes **795**, a coolant reservoir **787**, a first fluid pipe **788**, a third pump **789**, a second fluid pipe **790**, a third fluid pipe **792**, a fourth fluid pump **791**. The third pump **789** is adapted to pump a coolant, such as chilled water, towards the second heat exchanger **786** via the first fluid pipe **788**. The coolant flows through the tubes **795** and

is directed towards the second heat exchanger **786** via the second fluid pipe **790**. Further, the second heat exchanger **786** receives the third fluid exiting the second contactor panel **756** via the fourth fluid conduit **751**. The third fluid received within the second heat exchanger **786** flows over the tubes **795**. As the third fluid flows over the tubes **795**, a temperature of the third fluid decreases. Further, the third fluid pipe **792** directs the third fluid that is at a lower temperature towards the second tank **750** from where the third fluid may be directed towards the second contactor panel **756**. The fourth fluid pump **791** pressurized the third fluid towards the second tank **750**.

(69) FIG. **8** illustrates a fourth contactor system **800**, according to an embodiment of the present disclosure. The fourth contactor system **800** may be hereinafter interchangeably referred to as the contactor system **800**. In one example, the fourth contactor system **800** may be an evaporative cooling system. Such an evaporative cooling system may be similar to the evaporative cooling system **104** associated with the first contactor system **100** of FIG. **1**. In another example, the fourth contactor system **800** may be a dehumidification system. Such a dehumidification system may be similar to the dehumidification system **102** associated with the first contactor system **100** of FIG. **1**. The contactor system **800** includes a tank **802** adapted to hold a first fluid therein. In one example, the first fluid is at least one of a liquid and a gas. Further, the first fluid may include a liquid, a gas, a sweep gas, air, forced air, a vacuum, or combinations thereof. The liquid may include, for example, a cold and/or absorbent liquid, a salt solution, a hot and/or humidifying liquid, or a liquid desiccant. A type of the first fluid may vary based on an application of the contactor system **800**. Further, the contactor system **800** may also include a chilling module (not shown) that is similar to the chilling module **640** of the contactor system **600** explained in relation to FIG. **6**A. Such a chilling module may be used to lower a temperature of the first fluid being directed towards each contactor panel **818**.

(70) Further, the fourth contactor system **800** includes a blower unit **804** adapted to direct a second fluid towards at least one contactor panel array **806**. Although, a single blower unit **804** is illustrated herein, it should be noted that each contactor panel **818** may include individual blower units, without any limitations. In one example, the second fluid is at least one of a liquid and a gas. Further, the second fluid may include a liquid, a gas, a sweep gas, air, forced air, a vacuum, or combinations thereof. The liquid may include, for example, a cold and/or absorbent liquid, a salt solution, a hot and/or humidifying liquid, or a liquid desiccant. A type of the second fluid may vary based on an application of the contactor system **800**.

(71) Further, the contactor system **800** includes a first manifold **810** in selective fluid communication with a first end portion **830** of a membrane array **826** of each contactor panel **818** based on an operation of a valve assembly **838**. The first manifold **810** is adapted to direct the first fluid towards the membrane array **826** of each contactor panel **818**. Further, the contactor system **800** includes a second manifold **816** in direct fluid communication with a second end portion **824** of the membrane array **826** of each contactor panel **818**. The second manifold **816** is adapted to receive the first fluid from the membrane array **826** of each contactor panel **818**. The contactor system **800** also includes an inlet conduit **808** adapted to provide fluid communication between the tank **802** and the first manifold **810**.

(72) Further, a pump **812** is fluidly disposed between the inlet conduit **808** and the tank **802**. The pump **812** is positioned in the inlet conduit **808** and the tank **802**. The pump **812** pressurizes the first fluid to introduce the pressurized first fluid in the first manifold **810**. The contactor system **800** also includes an outlet conduit **814** adapted to provide fluid communication between the tank **802** and the second manifold **816**. Further, the fourth contactor system **800** includes the at least one contactor panel array **806**. In the illustrated embodiment, the fourth contactor system **800** includes a single contactor panel array **806** having a plurality of contactor panels **818**. The contactor panel array **806** includes the plurality of contactor panels **818** disposed adjacent to each other. Further, the tank **802** is in fluid communication with each contactor panel **818** via the inlet conduit **808** and the first manifold **810** for directing the first fluid towards each contactor panel **818**. The tank **802** is

also in fluid communication with each contactor panel **818** via the outlet conduit **814** and the second manifold **816** for directing the first fluid from each contactor panel **818** towards the tank **802**.

(73) Further, as described above the fourth contactor system **800** includes the plurality of contactor panels **818**. Each contactor panel **818** is similar to the first contactor panel **112** associated with the first contactor system **100** shown in FIG. **1**. Each contactor panel **818** includes a frame member **820**. The frame member **820** may be square or rectangular in shape. The frame member **820** of each contactor panel **818** defines a first headspace **828** that provides fluid communication between the first manifold **810** and the first end portion **830** of the membrane array **826**. Further, the frame member **820** of each contactor panel **818** defines a second headspace **822** that provides fluid communication between the second manifold **816** and the second end portion **824** of the membrane array **826**.

(74) Each contactor panel **818** includes the membrane array **826** adapted to be received within the frame member **820**. The membrane array **826** extends between the first headspace **828** and the second headspace **822**. The membrane array **826** defines the first end portion **830** and the second end portion **824**. The first end portion **830** is in fluid communication with the first headspace **828** and the second end portion **824** is in fluid communication with the second headspace **822**. The membrane array **826** includes a plurality of hollow fibers **832**.

(75) Further, the membrane array **826** of each contactor panel **818** is similar to the hollow fiber membrane array described in the '302 patent. It should be noted that details corresponding to a design, material, and manufacturing of the membrane array **826** is similar to a design, material, and manufacturing of the hollow fiber membrane array described in the '302 patent. The membrane array **826** of each contactor panel **818** is a microporous, hydrophobic, hollow fiber membrane array. The membrane array **826** of each contactor panel **818** includes at least one membrane layer that is similar to the membrane layer **148** explained in relation to FIG. **2**C. The at least one membrane layer includes the plurality of hollow fibers **832**. In some examples, each contactor panel **818** includes a plurality of membrane layers disposed adjacent to each other. The membrane array **826** of each contactor panel **818** is at least one of wound, pleated, and folded. More particularly, the membrane layers may be folded, pleated, or wound to form the membrane array **826** along a depth of the membrane array **826**. In the illustrated embodiment, the membrane array **826** includes sixty membrane layers, without any limitations. In another embodiment, the membrane array **826** may include twenty membrane layers or forty membrane layers, as per application requirements. Further, each membrane layer may include eight hollow fibers **832**. It may be contemplated that a total number of the membrane layers and a total number of the hollow fibers **832** may vary, as per application requirements. The number of membrane layers and the hollow fibers **832** may depend upon a desired efficiency of the contactor panel **818**. It should be noted that, in some examples, the efficiency of the contactor panel **818** may be increased by increasing the membrane layers and the hollow fibers **832**.

(76) The membrane array **826** includes the plurality of hollow fibers **832**. Further, each hollow fiber **832** includes a lumen **842** adapted to receive the first fluid. The lumen **842** may be hereinafter interchangeably referred to as a first portion **842**. Moreover, each hollow fiber **832** includes an exterior surface **844** adapted to contact a second fluid. The exterior surface **844** may be hereinafter interchangeably referred to as a second portion **844**. The blower unit **804** is adapted to direct the second fluid towards the exterior surface **844** of each hollow fiber **832**. A wall of each hollow fiber **832** separates the lumen **842** and the exterior surface **844**. The plurality of hollow fibers **832** are knitted together to form the membrane array **826**. The hollow fibers **832** are knitted similar to the knitting techniques described in relation to FIGS. **5**A and **5**B.

(77) Further, each contactor panel **818** includes a first conduit **834** fluidly connecting the first manifold **810** and the first end portion **830** of the membrane array **826**. The first conduit **834** may include a pipe or a tube that provides fluid communication between the first manifold **810** and the

first end portion **830** of the membrane array **826**. The first fluid exiting the tank **802** is received by the first end portion **830** via the inlet conduit **808**, the first manifold **810**, the first headspace **828**, and the first conduit **834**. Moreover, each contactor panel **818** also includes a second conduit **836** fluidly connecting the second manifold **816** and the second end portion **824** of the membrane array **826**. The second conduit **836** may include a pipe or a tube that provides fluid communication between the second manifold **816** and the second end portion **824** of the membrane array **826**. The first fluid exiting the membrane array **826** is received by the tank **802** via the second headspace **822**, the second conduit **836**, the second manifold **816**, and the outlet conduit **814**. It should be noted that a location of the first and second conduits **834**, **836** illustrated herein is exemplary in nature. Accordingly, the first and second conduits **834**, **836** may be connected to a side surface, a front surface, or a rear surface of the frame member **820**.

(78) Further, each contactor panel **818** includes the valve assembly **838** in fluid communication with the first end portion **830** of the membrane array **826**. The valve assembly **838** is disposed in the first conduit **834** and provides selective fluid communication between the first manifold **810** and the first end portion **830** of the membrane array **826**. The valve assembly **838** may include a solenoid that may be energized/deenergized to open or close the valve assembly **838**. The valve assembly **838** may be opened to provide fluid communication between the first manifold **810** and the first end portion **830** of the membrane array **826**. Further, the valve assembly **838** may be closed to restrict fluid communication between the first manifold **810** and the first end portion **830** of the membrane array **826**. It should be noted that the contactor panel **818** may be activated or deactivated based on opening or closing of the corresponding valve assembly **838**. The opening of the valve assembly **838** causes the first fluid to flow through the hollow fibers **832**. Further, the second fluid contacts the first fluid causing the mass and/or heat transfer based on the contact between the first and second fluids. Thus, one more characteristics of the second fluid may vary based on the contact between the first and second fluids. Further, when the valve assembly **838** is closed, the contactor panel **818** may not cause any change in the mass and/or heat content of the second fluid.

(79) The contactor system **800** includes a controller **840** configured to provide selective fluid communication between the first manifold **810** and the first end portion **830** of the membrane array **826** of each contactor panel **818**. The controller **840** is communicably coupled with the valve assembly **838** of each contactor panel **818**. More particularly, the controller **840** may be communicably coupled with the solenoids of the respective valve assemblies **838**. The controller **840** is configured to selectively control the valve assembly **838** of at least one contactor panel **818**. More particularly, one or more contactor panels **818** may be activated or deactivated based on control of the valve assembly **838** associated with the corresponding contactor panel **818**. The controller **840** is configured to selectively control the valve assembly **838** of the at least one contactor panel **818** based on at least one of a high thermal load location, a target temperature, a target humidity, and a temperature uniformity metric. More particularly, the one or more contactor panels **818** may be activated or deactivated based on control of the valve assembly **838** associated with the corresponding contactor panels **818** so that a temperature or a humidity at the high thermal load location may be lowered or the temperature uniformity metric may be brought closer to its ideal value of 100%. Useful temperature uniformity metrics can include return temperature index (RTI®), rack cooling index-high (RHI®), or rack cooling index-low (RCI®).

(80) Further, one or more contactor panels **818** may be activated based on the target temperature, the target humidity, and/or the temperature uniformity metric. The target temperature, the target humidity, and/or the temperature uniformity metric may be based on a desired efficiency. The controller **840** is also configured to control the valve assembly **838** to vary a flow rate of the first fluid flowing through the valve assembly **838** of the at least one contactor panel **818**. The flow rate of the first fluid may depend on the high thermal load location, the target temperature, the target humidity, and/or the temperature uniformity metric. For this purpose, the controller **840** may

control a degree of opening of the valve assembly **838** associated with the contactor panel **818** that needs to be activated. Based on the control of the degree of opening of one or more valve assemblies **838**, the temperature and/or humidity may be efficiently controlled as per requirements.

(81) In one example, wherein the contactor system **800** is embodied as the evaporative cooling system, the contactor system **800** may be used to vary the temperature and humidity of the second fluid based on the heat and mass transfer between the first and second fluids. A control of the contactor system **800** by the controller **840** will now be explained. For exemplary purposes, a control technique applied by the controller **840** is illustrated in reference to the evaporative cooling system, however, the details provided herein are equally applicable to other systems such as a dehumidification system, a humidification system, or a heating system. It should be noted that the contactor panels **818** may be activated or deactivated based on the high thermal load location, the target temperature, the target humidity, and/or the temperature uniformity metric. If the target temperature is higher than a current temperature setting, the controller **840** may open the valve assembly **838** of some contactor panels **818**. Accordingly, some of the contactor panels **818** will be in an activated state. The contactor panels **818** in the activated state may release cool and humid air, whereas the contactor panels **818** in the deactivated state may simply allow passage of dry and hot air. Thus, the cool and humid air may blend with the dry and hot air to increase the current temperature to the target temperature. Further, if the target temperature corresponds to a lowest temperature setting, the controller **840** may open the valve assembly **838** of all the contactor panels **818**. Accordingly, all the contactor panels **818** will be in an activated state to release cool and humid air to lower the current temperature to the target temperature. Thus, it should be noted that a number of the contactor panels **818** that need to be operated in the activated state may depend on the high thermal load location, the target temperature, the target humidity, and/or the temperature uniformity metric. In some examples, the controller **840** may operate such that a uniform temperature/humidity is maintained across a room or area. Further, in another example, wherein the contactor system **800** is a dehumidification system, the contactor panels **818** may be activated or deactivated to vary the humidity of the second fluid based on the mass transfer between the first and second fluids.

(82) FIG. **9** illustrates another embodiment of the present disclosure. In this embodiment, a contactor system **900** includes a plurality of contactor panel arrays **906** spaced apart from each other. In the illustrated embodiment, the contactor system **900** includes three contactor panel arrays **906**. However, a total number of the contactor panel arrays **906** may vary as per application requirements. Further, each contactor panel array **906** includes four contactor panels **918**. Each contactor panel **918** includes a membrane array **926** similar to the membrane array **132** associated with the first contactor system **100** described in relation to FIG. **1**. Further, the membrane array **926** includes a plurality of hollow fibers **932**.

(83) The contactor system **900** includes an inlet conduit **908**, an outlet conduit **914**, a pump (not shown), and a blower unit (not shown) similar to the inlet conduit **808**, the outlet conduit **814**, the pump **812**, and the blower unit **804** associated with the fourth contactor system **800**. Further, the plurality of contactor panel arrays **906** includes different first manifolds **910** and different second manifolds **916**. More particularly, the contactor system **900** includes three first manifolds **910** and three second manifolds **916**. Each first manifold **910** is in fluid communication with the inlet conduit **908**. Moreover, each contactor panel **918** is in fluid communication with the first manifold **910** via a first conduit **934**. Further, each second manifold **816** is in fluid communication with the outlet conduit **914**. Moreover, each contactor panel **918** is in fluid communication with the second manifold **816** via a second conduit (not shown) that is similar to the first conduit **934**.

(84) A valve assembly **938** is disposed in the first conduit **834**. An operation and details of the valve assembly **938** is similar to the valve assembly **838** of the fourth contactor system **800** described in relation to FIG. **8**. The contactor system **900** also includes a controller (not shown). The controller controls the valve assembly **938** of each contactor panel **918** to activate or deactivate one or more

contactor panels **918** based on application requirements. It should be noted that installation of multiple contactor panels **818**, **918** and multiple contactor panel arrays **806**, **906** instead of the single contactor panel may demonstrate improved efficiency, allow easier replacement of the contactor panels **818**, **918**, convenient storage/handling of the contactor panels **818**, **918**, lower replacement costs, and/or the like. Further, the contactor system **800**, **900** may allow improved control over the temperature and the humidity of the second fluid being released by the contactor panel **818**, **918**. It should be noted that the contactor systems **800**, **900** may allow judicious utilization of the first fluid as the contactor panels **819**, **918** may be selectively activated. Moreover, the contactor system **800**, **900** may also allow recirculation of water at a constant temperature due to installation of common first manifolds **810**, **910** and second manifolds **816**, **916**. Further, the control of the flow rate of the first fluid, and in some cases the temperature of the first fluid, may allow efficient running of the contactor system **800**, **900** at partial and/or low load conditions.
(85) Further, the contactor system **800**, **900** described herein provides increased usability rate as a drying time associated with the contactor panel **818**, **918** may be lower as compared to conventional contactor panels. The increase in usability rate may in turn allow precise control of the temperature and humidity of the second fluid. For example, as the membrane array **826**, **926** associated with the contactor panel **818**, **918** may dry at a faster rate, the second fluid being released by the contactor panel **818**, **918** may reach the target temperature and humidity in a shorter time period.
(86) As illustrated in FIGS. **10**A and **10**B, a housing member **1002** is adapted to receive at least one contactor panel **818** (see FIG. **8**) or at least one contactor panel **918** (see FIG. **9**) of the plurality of contactor panels **818**, **918**. The housing member **1002** defines a first longitudinal axis "L-L**1**". A dimension of the housing member **1002** described herein is exemplary in nature, and the dimension of the housing member **1002** may vary as per application requirements. The housing member **1002** may receive a single contactor panel **818**, **918** or a pair of the contactor panels **818**, **918**. It should be noted that an orientation of the contactor panel **818**, **918** relative to the housing member **1002** may be varied based on application requirements. More particularly, as the contactor panel **818**, **918** is associated with the contactor system **800**, **900** embodied as a closed loop system, the contactor panel **818**, **918** may be installed in various orientations as evident from FIGS. **10**A to **10**D. In one example, as illustrated in FIG. **10**A, the contactor panel **818**, **918** is positioned within the housing member **1002** such that each hollow fiber **832**, **932** (see FIGS. **8** and **9**) of the membrane array **826**, **926** of the at least one contactor panel **818**, **918** defines a second longitudinal axis "B-B**1**" that extends substantially perpendicular to the first longitudinal axis "L-L**1**" defined by the housing member **1002**. In another example, as illustrated in FIG. **10**B, the contactor panel **818**, **918** is positioned within the housing member **1002** such that each hollow fiber **832**, **932** (see FIGS. **8** and **9**) of the membrane array **826**, **926** of the at least one contactor panel **818**, **918** defines the second longitudinal axis "B-B**1**" that extends substantially parallel to the first longitudinal axis "L-L**1**" defined by the housing member **1002**.
(87) Referring now to FIG. **10**C, the contactor panel **818**, **918** may also be disposed horizontally. In such examples, the first fluid from a tank **1008** may be pressurized and directed towards the contactor panel **818**, **918** via a first fluid conduit **1010**. The first fluid returns to the tank **1008** via a second fluid conduit **1012**. The tank **1008**, the first fluid conduit **1010**, and the second fluid conduit **1012** may be similar to the first tank **106**, the first fluid conduit **110**, and the second fluid conduit **128** of the contactor system **100** described in relation to FIG. **1**. A flow of the first fluid through the contactor panel **818**, **918** is illustrated by the first fluid flow "F**1**". Further, the second fluid may flow over the contactor panel **818**, **918**. A flow of the second fluid is illustrated by the second fluid flow "F**2**". Thus, the contactor panel **818**, **918** described herein may be used in applications that have limitations in terms of vertical space availability or applications that demand installation of the contactor panel **818**, **918** in a specific orientation based on a shape, a size, and an orientation of the housing member **1002** (see FIGS. **10**A and **10**B) that receives the contactor panel **818**, **918**.

(88) As shown in FIG. **10**D, the contactor panel **818**, **918** may be disposed in an angular orientation. In such examples, the first fluid from the tank **1008** may be pressurized and directed towards the contactor panel **818**, **918** via the first fluid conduit **1010**. The first fluid returns to the tank **1008** via the second fluid conduit **1012**. The flow of the first fluid through the contactor panel is illustrated by the first fluid flow "F**1**". Further, the second fluid may flow over the contactor panel **818**, **918**. The flow of the second fluid is illustrated by the second fluid flow "F**2**". Thus, the contactor panel **818**, **918** described herein may be used in applications that demand installation of the contactor panel **818**, **918** in a specific orientation based on the shape, the size, and the orientation of the housing member **1002** (see FIGS. **10**A and **10**B) that receives the contactor panel **818**, **918**.
(89) Referring now to FIG. **11**, in one example, the housing member **1002** is disposed proximate an area towards which the second fluid need to be directed. Thus, the contactor panels **818**, **918** may be arranged such that one or more contactor panels **818**, **918** are received within the housing member **1002** proximate the area towards which the second fluid need to be directed. Further, FIG. **11** illustrates a number of electronic devices **1102**, such as servers, installed in a room **1104**. The room **1104** may embody a data center. Further, the housing member **1002** is disposed in at least one of a ceiling **1112**, a floor **1110**, and a wall **1114** of the room **1104**. The room **1104** may include a number of hot spots that may typically have a high temperature. In some examples, the contactor panels **818**, **918** may be arranged proximate such hot spots in the room **1104**. The housing member **1002** may receive one or more contactor panels **818**, **918**. The positioning of the housing member **1002**, and more specifically the one or more contactor panels **818**, **918**, in the ceiling **1112**, the floor **1110**, and/or the wall **1114** of the room **1104** may allow the room **1104** to reach a uniform temperature/humidity or the target temperature/humidity. Further, the room **1104** may include a number of the contactor panels **818**, **918**. As illustrated, the one or more contactor panels **818**, **918** is positioned proximate an aisle **1108**. Further, grills **1106** may be provided in alignment with the aisle **1108** to allow air, such as cool and humid air, to be directed towards the room **1104**. More particularly, the contactor panels **818**, **918** is positioned in the ceiling **1112**. However, the contactor panels **818**, **918** may also be positioned within the floor **1110** or the wall **1114**. In some examples, the room **1104** may have designated hot spots and the contactor panel **818**, **918** may be positioned proximate such designated hot spots.
(90) It should be further noted that the contactor panels **818**, **918** may be selectively controlled using the valve assembly, similar to the valve assembly **838** (see FIG. **8**) and a controller, similar to the controller **840** (see FIG. **8**), in order to activate the contactor panels **818**, **918** to maintain the uniform temperature/humidity and/or to achieve the target temperature/humidity. The arrangement illustrated herein allows positioning of the contactor panels **818**, **918** proximate the area towards which the second fluid is directed so that the uniform temperature/humidity can be maintained in the entire area in an efficient and economic manner while utilizing low amount of fan power, water usage, and may result in an increase in a coefficient of performance of the evaporative cooling system.
(91) FIG. **12** illustrates yet another embodiment of a contactor system **1200**. In this embodiment, the contactor system **1200** includes a tank **1202**, a pump **1204**, and a blower unit **1206** similar to the first tank **106**, the first pump **108**, and the first blower unit **114** of the contactor system **100** explained in relation to FIG. **1**. Further, the contactor system **100** includes a number of contactor panel arrangements **1208**. The contactor system **1200** illustrated herein includes three contactor panel arrangements **1208**. However, a total number of the contactor panel arrangements **1208** may vary as per application requirements. Further, each contactor panel arrangement **1208** includes a number of membrane arrays **1210**. In the illustrated example, each contactor panel arrangement **1208** includes three membrane arrays **1210**. Further, each membrane array **1210** is embodied as a bundle having a number of hollow fibers **1212**. Each hollow fiber **1212** is similar to the hollow fiber **138** associated with the contactor system **100** described in relation to FIG. **2**B.

(92) Further, each contactor panel arrangement **1208** includes a first headspace **1214** and a second headspace **1216**. A frame member (not shown) may support the membrane arrays **1210**, the first headspace **1214**, and the second headspace **1216**. In the illustrated example, the first and second headspaces **1214**, **1216** are in fluid communication with the tank **1202**. More particularly, a first fluid conduit **1220** fluidly connects the tank **1202** with the first headspace **1214**. The pump **1204** is disposed in the first fluid conduit **1220**. Further, a second fluid conduit **1222** fluidly connects the tank **1202** with the second headspace **1216**. Each contactor panel arrangement **1208** is in fluid communication with an adjacent contactor panel arrangement **1208** by a fluid pipe **1224**. In the illustrated example, the second headspace **1216** is in fluid communication with the first headspace **1214** of the adjacent contactor panel arrangement **1208** by the fluid pipe **1224**. In other examples, the second headspace **1216** may be in fluid communication with the second headspace **1216** of the adjacent contactor panel arrangement **1208** by the fluid pipe **1224**. In yet other examples, the first headspace **1214** may be disposed in fluid communication with the first headspace **1214** or the second headspace **1216** of the adjacent contactor panel arrangement **1208** by the fluid pipe **1224**.
(93) Further, the first headspace **1214** includes a number of first conduits **1226** and a number of second conduits **1228** in fluid communication with each other. The second conduits **1228** are in fluid communication with the membrane arrays **1210**. The second headspace **1216** includes a number of third conduits **1230** and a number of fourth conduits **1232** in fluid communication with each other. The fourth conduits **1232** are in fluid communication with the membrane arrays **1210**.
(94) Further, in order to couple each membrane array **1210** with the first and second headspaces **1214**, **1216**, a first end **1234** and a second end **1236** of each hollow fiber **1212** is potted sealed with the second and fourth conduits **1228**, **1232**, respectively, using a potting material. The ends **1234**, **1236** may be embedded in a resin by potting methods, such as gravity potting method, mold potting method, centrifugal potting method, and the like. The potting material may include epoxy, thermoplastics, polyurethane, etc. The potting material may seal each hollow fiber **1212** to the first headspace **1214** and the second headspace **1216**. It should be noted that the ends **1234**, **1236** are potted sealed such that a lumen of each hollow fiber **1212** is in fluid communication with the first headspace **1214** and the second headspace **1216**, respectively.
(95) Referring now to FIG. **13**, an exemplary set-up **1300** that was used for conducting a series of experiments to compare performance of a contactor panel **1302** with conventional contactor panels including wetted cellulosic media is illustrated. The contactor panel **1302** is similar to the first contactor panel **112** associated with the first contactor system **100** of FIG. **1**. The set-up **1300** illustrated herein was used to calculate a cooling effectiveness of the contactor panel **1302** having a membrane array **1304**. As illustrated, a tank **1306** containing water was fluidly coupled with the membrane array **1304** using a first fluid conduit **1310** and a second fluid conduit **1312**. The membrane array **1304** was a 60 layered membrane array. Moreover, a blower unit **1308** was disposed proximate the membrane array **1304** for pulling air through the membrane array **1304**. Further, the set-up **1300** included a number of thermocouples for measuring an inlet temperature of inlet air and an outlet temperature of outlet air. The set-up **1300** also included humidity sensor to measure an inlet relative humidity and an outlet relative humidity of the inlet air and the outlet air.
(96) Further, the inlet temperature, the inlet relative humidity, and an inlet specific enthalpy of the inlet air before contacting the membrane array **1304** was approximately equal to 23° Celsius (C), 5%, and 25 kilo Joules/kilograms (kJ/kg), respectively. An inlet temperature of the water entering hollow fibers of the membrane array **1304** was approximately equal to 15° C. Moreover, a pump (not shown) was disposed in the first fluid conduit **1310** to direct fluid through the hollow fibers. Further, cool, and humid air was released by the contactor panel **1302** based on contact between the water flowing through a lumen of each hollow fiber of the membrane array **1304** and the air flowing over an exterior surface of each hollow fiber of the membrane array **1304**. The outlet temperature, an outlet relative humidity, and an outlet specific enthalpy of the outlet air was approximately equal to 16° C., 84%, and 40 kJ/kg, respectively. Further, a difference in the inlet

specific enthalpy and the outlet specific enthalpy was approximately equal to 15 kJ/kg. Moreover, a saturation effectiveness and the cooling effectiveness of the contactor panel **1302** was calculated. From the calculations, it was concluded that the saturation effectiveness and the cooling effectiveness of the contactor panel **1302** was approximately equal to 0.48 and 44%, respectively. It should be noted that the term “saturation effectiveness” referred to herein is defined as a ratio of a difference between an inlet drub temperature and an outlet dry bulb temperature to a wet bulb depression. The inlet dry bulb temperature is the dry bulb temperature of the inlet air, the outlet dry bulb temperature is the dry bulb temperature of the outlet air. Moreover, the wet bulb depression is a difference between the inlet dry bulb temperature and a wet bulb temperature of the inlet air.

(97) Further, a similar set-up was used to calculate a saturation effectiveness and a cooling effectiveness of a conventional contactor panel fitted with the wetted cellulosic media. An inlet temperature and an inlet relative humidity of inlet air before contacting the wetted cellulosic media was similar to the inlet temperature and the inlet relative humidity of the inlet air before contacting the membrane array **1304** of the contactor panel **1302**. It was concluded from this experiment that the contactor panel **1302** with the membrane array **1304** exhibits improved saturation effectiveness and cooling effectiveness compared with the conventional contactor panel fitted with the wetted cellulosic media.

(98) FIG. **14** illustrates an exemplary plot **1400**. Various values for velocity (in meters per second) of inlet air are marked on X-axis and various values for saturation effectiveness are marked on Y-axis. Further, the plot **1400** illustrates a first curve **1402** that was plotted based on experiments on a contactor panel, similar to the contactor panel **112** associated with the first contactor system **100** of FIG. **1**, with a 60 layered membrane array at high water flow rate. Moreover, a second curve **1404** was plotted based on experiments on a contactor panel, similar to the contactor panel **112** associated with the first contactor system **100** of FIG. **1**, with a 20 layered membrane array at low water flow rate. Additionally, a third curve **1406** was plotted based on experiments on a contactor panel, similar to the contactor panel **112** associated with the first contactor system **100** of FIG. **1**, with a 20 layered membrane array at high water flow rate. The saturation effectiveness exhibited by the contactor panels at different velocities were plotted to generate the curves **1402**, **1404**, **1406**. From the plot **1400**, it can be concluded that the contactor panel with the 60 layered membrane array exhibits improved saturation effectiveness as compared to the contactor panels with the 20 layered membrane array.

(99) It should be noted that the contactor systems **100**, **600**, **700**, **800**, **900**, **1200** described herein can be used in large scale applications, such as in datacenters. The contactor systems **100**, **600**, **700**, **800**, **900**, **1200** may embody evaporative cooling systems for cooling the datacenters. Further, the contactor systems **100**, **600**, **700**, **800**, **900**, **1200** may also be used in other outdoor evaporative cooling applications. The contactor systems **100**, **600**, **700**, **800**, **900**, **1200** can be used in other applications for heating, cooling, humidifying, and/or dehumidifying, without limiting the scope of the present disclosure. The contactor panels **112**, **156**, **400**, **500**, **612**, **712**, **756**, **818**, **918** and the contactor panel arrangement **1208** may also exhibit improved cooling performance in a smaller footprint.

(100) Further, the contactor systems **100**, **600**, **700**, **800**, **900**, **1200** may allow usage of different types of membrane arrays **132**, **170**, **402**, **632**, **732**, **770**, **826**, **926**, **1210** such as a hollow fiber membrane (including a capillary membrane), a flat sheet membrane, a ceramic membrane, and the like, thereby increasing flexibility of the contactor systems **100**, **600**, **700**, **800**, **900**, **1200**. The membrane arrays **132**, **170**, **402**, **632**, **732**, **770**, **826**, **926**, **1210** may provide faster drying time as compared to conventional membranes and also allow independence of gravity for directing the first fluid. Moreover, the membrane arrays **132**, **170**, **402**, **632**, **732**, **770**, **826**, **926**, **1210** may also be used in adaptive contactor systems, such as the contactor systems **800**, **900**. Additionally, the membrane arrays **132**, **170**, **402**, **632**, **732**, **770**, **826**, **926**, **1210** may allow flexibility in placement of the contactor panels **112**, **156**, **400**, **500**, **612**, **712**, **756**, **818**, **918** and the contactor panel

arrangement **1208** proximate to hot spots, in floors/walls/ceilings, or at different orientations based on design and space availability of an installation area.

(101) When used in evaporative cooling systems, the contactor panels **112**, **156**, **400**, **500**, **612**, **712**, **756**, **818**, **918** and the contactor panel arrangement **1208** described in this disclosure may require a reduced quantity of water for operation thereof, due to high water vapor efficiency. Thus, the contactor panels **112**, **156**, **400**, **500**, **612**, **712**, **756**, **818**, **918** and the contactor panel arrangement **1208** may be used at locations where there may be a scarcity of water. Further, the contactor panels **112**, **156**, **400**, **500**, **612**, **712**, **756**, **818**, **918** and the contactor panel arrangement **1208** may exhibit reduced sensitivity to water quality. Moreover, the contactor panel **112**, **156**, **400**, **500**, **612**, **712**, **756**, **818**, **918** and the contactor panel arrangement **1208** may be interchangeably used for different applications, such as humidifying or dehumidifying. It should be noted that the contactor panels **112**, **156**, **400**, **500**, **612**, **712**, **756**, **818**, **918** and the contactor panel arrangement **1208** associated with the contactor system **100**, **600**, **700**, **800**, **900**, **1200** described herein may be used in large scale applications, such as in data centers. For example, the contactor panel **112**, **156**, **400**, **500**, **612**, **712**, **756**, **818**, **918** and the contactor panel arrangement **1208** may be associated with the evaporative cooling system for cooling the data centers, other rooms installed with electronic devices, commercial applications, and the like. Further, the contactor panel **112**, **156**, **400**, **500**, **612**, **712**, **756**, **818**, **918** and the contactor panel arrangement **1208** may be used in various applications for heating, cooling, humidifying, and/or dehumidifying, without limiting the scope of the present disclosure. Moreover, the contactor panel **112**, **156**, **400**, **500**, **612**, **712**, **756**, **818**, **918** and the contactor panel arrangement **1208** may provide improved performance in a compact footprint. Further, the contactor panels **112**, **156**, **400**, **500**, **612**, **712**, **756**, **818**, **918** may allow both latent heat transfer and sensible heat transfer during operation. Accordingly, such contactor panels **112**, **156**, **400**, **500**, **612**, **712**, **756**, **818**, **918** operating at higher air flow velocities may demonstrate higher saturation effectiveness. This phenomenon may in turn allow designing of air handlers with a compact frontal area as compared to air handlers running with conventional media that may only allow latent heat transfer.

(102) Further, the contactor panels **112**, **156**, **400**, **500**, **612**, **712**, **756**, **818**, **918** and the contactor panel arrangement **1208** may provide high structural integrity, which may in turn provide increased sustenance against higher liquid pressure without damaging a structure of the contactor panel **112**, **156**, **400**, **500**, **612**, **712**, **756**, **818**, **918** and the contactor panel arrangement **1208**. It should be further noted that the contactor panels **112**, **156**, **400**, **500**, **612**, **712**, **756**, **818**, **918** and the contactor panel arrangement **1208** may be constructed based on customer's requirement, geographic areas, and climatic conditions at customer's location. Thus, the contactor panels **112**, **156**, **400**, **500**, **612**, **712**, **756**, **818**, **918** and the contactor panel arrangement **1208**, and the various arrangements of the contactor panel **112**, **156**, **400**, **500**, **612**, **712**, **756**, **818**, **918** and the contactor panel arrangement **1208** may allow flexibility in installation and usage. Further, the contactor panel **112**, **156**, **400**, **500**, **612**, **712**, **756**, **818**, **918** and the contactor panel arrangement **1208** described herein may be retrofitted in existing contactor systems with minimum alterations to a design of the existing contactor systems.

(103) FIG. **15** illustrates a flowchart for a method of operating the contactor system **800**. The method **1500** will be explained in relation to the contactor system **800** shown in FIG. **8**. However, it should be noted that the method **1500** is equally applicable to other contactor systems **100**, **600**, **700**, **900**, **1200**. At step **1502**, the first fluid is introduced within the first manifold **810** of the contactor system **800**. The first manifold **810** is in fluid communication with the tank **802** for directing the first fluid towards the first manifold **810**. The contactor system **800** further includes the second manifold **816**, the plurality of contactor panels **818**, and the controller **840**. Each contactor panel includes the membrane array **826** and the valve assembly **838**. In an example, the contactor panel array **806** includes the plurality of contactor panels **818** disposed adjacent to each other. In another example, the plurality of contactor panel arrays **806** are spaced apart from each

other. Further, in some examples, the plurality of contactor panels **818** are positioned in at least one of the ceiling **1112**, the floor **1110**, and the wall **1114** of the room **1104**. In some examples, the plurality of contactor panels **818** are positioned in at least one of the evaporative cooling system, the dehumidification system, and a combination thereof.

(104) At step **1504**, the controller **840** controls the valve assembly **838** associated with at least one contactor panel **818** for providing selective fluid communication between the first manifold **810** and the membrane array **826** of the at least one contactor panel **818**. At step **1506**, the first fluid is introduced within the membrane array **826** of the at least one contactor panel **818** based on control of the valve assembly **838** associated with the at least one contactor panel **818**. Further, the first fluid is introduced within the first portion **842** of the membrane array **826** including at least one of the plurality of hollow fibers **832**, the flat sheet membrane, and a combination thereof. More particularly, the first fluid is introduced within the lumen **842** of each hollow fiber **832** of the plurality of hollow fibers **832** of the at least one contactor panel **818**.

(105) At step **1508**, at least one characteristic of the second fluid flowing over the membrane array **826** of the at least one contactor panel **818** is controlled based on at least one of the mass transfer and the heat transfer between the first fluid flowing through the membrane array **826** of the at least one contactor panel **818** and the second fluid flowing over the membrane array **826** of the at least one contactor panel **818**. The at least one characteristic of the second fluid includes the temperature and the humidity. The second fluid contacts with the second portion **844** of the membrane array **826**. More particularly, the second fluid contacts with the exterior surface **844** of each hollow fiber **832** of the plurality of hollow fibers **832** of the at least one contactor panel **818**. Further, the controller **840** controls the valve assembly **838** of the at least one contactor panel **818** based on at least one of the high thermal load location, the target temperature, the target humidity, and the temperature uniformity metric. More particularly, the controller **840** controls the valve assembly **838** to vary the flow rate of the first fluid flowing through the valve assembly **838** of the at least one contactor panel **818**.

(106) Further, the housing member **1002** is adapted to receive at least one contactor panel **818** of the plurality of contactor panels **818**. The housing member **1002** defines the first longitudinal axis “L-L**1**”. In an example, the at least one contactor panel **818** is received within the housing member **1002** such that the second longitudinal axis “B-B**1**” defined by the membrane array **826** of the at least one contactor panel **818** extends substantially perpendicular to the first longitudinal axis “L-L**1**” defined by the housing member **1002**. In another example, the at least one contactor panel **818** is received within the housing member **1002** such that the second longitudinal axis “B-B**1**” defined by the membrane array **826** of the at least one contactor panel **818** extends substantially parallel to the first longitudinal axis “L-L**1**” defined by the housing member **1002**.

(107) Further, in some examples, at least one separator structure **404** (see FIG. **4**) is positioned adjacent to the membrane array **402** (see FIG. **4**). Moreover, at least two membrane arrays **402** may be positioned adjacent to each other. In some examples, the chilling module **640** (see FIG. **6**A) is fluidly coupled with the tank **606** (see FIG. **6**A). The chilling module **640** includes the coolant reservoir **646** (see FIG. **6**A), the heat exchanger **642** (see FIG. **6**A) in fluid communication with the coolant reservoir **646** and the tank **602**, and the coolant pump **650** (see FIG. **6**A) fluidly disposed between the tank **606** and the heat exchanger **642**.

(108) Various embodiments of the invention have been described. These and other embodiments are within the scope of the following claims.

Claims

1. A contactor system comprising: a plurality of contactor panels, each contactor panel including: a frame member; and a membrane array adapted to be received within the frame member, the membrane array defining a first end portion and a second end portion; a first manifold in selective

fluid communication with the first end portion of the membrane array of each contactor panel, the first manifold being adapted to direct a first fluid towards the membrane array of each contactor panel; a second manifold in direct fluid communication with the second end portion of the membrane array of each contactor panel, the second manifold being adapted to receive the first fluid from the membrane array of each contactor panel; a controller configured to provide selective fluid communication between the first manifold and the first end portion of the membrane array of each contactor panel; a tank adapted to hold the first fluid therein; an inlet conduit adapted to provide fluid communication between the tank and the first manifold; an outlet conduit adapted to provide fluid communication between the tank and the second manifold; and a chilling module fluidly coupled with the tank, the chilling module including: a coolant reservoir; a heat exchanger in fluid communication with the coolant reservoir and the tank; and a coolant pump fluidly disposed between the tank and the heat exchanger.

2. The contactor system of claim 1, wherein each contactor panel further includes: a first conduit fluidly connecting the first manifold and the first end portion of the membrane array; and a second conduit fluidly connecting the second manifold and the second end portion of the membrane array.

3. The contactor system of claim 2, wherein each contactor panel further includes a valve assembly disposed in the first conduit and providing selective fluid communication between the first manifold and the first end portion of the membrane array.

4. The contactor system of claim 3, wherein the controller is communicably coupled with the valve assembly of each contactor panel, and wherein the controller is configured to selectively control the valve assembly of at least one contactor panel.

5. The contactor system of claim 4, wherein the controller is configured to selectively control the valve assembly of the at least one contactor panel based on at least one of a high thermal load location, a target temperature, a target humidity, and a temperature uniformity metric.

6. The contactor system of claim 4, wherein the controller is configured to control the valve assembly to vary a flow rate of the first fluid flowing through the valve assembly of the at least one contactor panel.

7. The contactor system of claim 1, wherein the frame member of each contactor panel defines a first headspace that provides fluid communication between the first manifold and the first end portion of the membrane array.

8. The contactor system of claim 1, further comprising a pump fluidly disposed between the inlet conduit and the tank.

9. The contactor system of claim 1, wherein the membrane array in each of the contactor panels includes at least one of a plurality of hollow fibers, a flat sheet membrane, and a combination thereof.

10. The contactor system of claim 9, wherein each hollow fiber includes a capillary membrane.