

DEW-POINT COOLER

Field of the Invention

The present invention is directed to an evaporative cooling system.

Background of the Invention

5 Air conditioners have been widely employed for controlling the temperature and the humidity of air in order to provide thermal comfort as well as a hospitable environment for storing goods and equipment in commercial buildings, residential houses, data centre, hospital, schools, industrial houses, supermarket, transportation means, etc. As the population grows, incomes rise around the world and global temperatures go up, demand for air conditioners is
10 increasing.

Ever since the refrigerant cycle was invented, the air conditioning systems have been dominated by the mechanical vapour compression chillers. However, the rise in air conditioning usage will have a significant impact on climate change. It is one of the key drivers of global electricity demand growth. It is estimated that improving air-conditioners
15 could do more than anything else to reduce greenhouse gases.

In order to achieve a quantum reduction in energy consumption and greenhouse gas emission for providing air-conditioning thermal comfort to occupants, several alternative technologies have been studied, such as absorption/adsorption chillers and evaporative coolers. Among these approaches, evaporative coolers have a lot of advantages and merits, including high
20 energy efficiency, low capital and operational costs, ease of installation and maintenance, no greenhouse gas emission, and no heat rejection to the environment.

Evaporative coolers work by exploiting water's large enthalpy of vaporization. Process air temperature is lowered via the evaporation of water. Evaporative coolers could be classified into direct evaporative coolers and indirect evaporative coolers.

25 In evaporative coolers, in order to achieve the product air temperature below the wet-bulb temperature and close to the dew-point temperature, the working air must be cooled before contacting with water. In conventional M-cycle cooler, a large portion (around 40-50%) of the product air is diverted to the wet channels to be the working air, resulting only 50-60% of the product air to be useful. As the result, the commercial M-cycle cooler has low cooling
30 capacity and low energy efficiency.

Therefore, there is a need for an improved evaporative cooler that overcomes the above problems.

Summary of the Invention

5 In a first aspect, the invention provides an evaporative cooling system comprising: a dry channel arranged to receive a process air stream and vent a product air stream; and a plurality of wet channels in a heat transfer communication with the dry channel, in which the wet channels are arranged to cool the dry channel through an evaporative process, wherein a portion of the product air from the dry channel is received as a process air stream by a first of the wet channels.

10 The evaporative cooling system may reduce the required portion (to 10-15%) of product air to be used as the working air to achieve the same cooling temperature. As a result, a larger portion (85-90%) of product air may be useful. This cooling system may realize a higher cooling capacity and higher energy efficiency.

15 In an embodiment, the dry channel may be divided into a first stage, in a heat transfer communication with a subsequent wet channel, and a second stage in a heat transfer communication with the first wet channel.

Cooling process air in multiple stages allows a smaller portion of the product air from the dry channel to be diverted to the wet channels, while ensuring homogenous and efficient heat transfer in the dry channel.

20 In an embodiment, the subsequent wet channel may be arranged to receive a working air from an ambient source.

The working air drives the evaporative cooling process.

25 In an embodiment, the plurality of wet channels may be in series, such that a portion of process air entering a downstream wet channel may be received from a product air stream from an upstream wet channel.

Wet channels may be arranged in series to allow the process air to be cooled in several stages. For example, the process air may be first cooled to reach a temperature close to the wet-bulb temperature, and then further cooled to reach a temperature close to the dew-point

temperature. In this way, the cooling capacity and energy efficiency of the system may be increased.

In an embodiment, a portion of the product air from the dry channel may be received as a process air stream by a first of the wet channels.

- 5 The portion of the product air from the dry channel may be pre-cooled, which may increase the cooling capacity when it enters the wet channel as a process air stream. This may also increase energy efficiency of the system.

In an embodiment, streams in the plurality of wet channels may be arranged along a path at an angle to the air stream path of the dry channel.

- 10 The air streams may be diverted at an angle to ensure minimal backflow, thus ensuring smooth air flow and further enhancing energy efficiency of the system.

In an embodiment, the angle may be 90°.

- Diverting the air streams at 90° may minimise the area needed for the portion of the product air to flow to the wet channels while minimising backflow into the dry channel. It would be appreciated that the system configuration may be modified to accommodate different angles and airflow speeds.
- 15

In an embodiment, the dry channel may include walls on opposed sides of the channel, and said wet channels in contact with both of said walls.

- A dry channel may be positioned next to a wet channel to ensure that the portion of the product air travels a minimum distance to the wet channel. This may improve cooling efficiency and enable the system to be compact.
- 20

In an embodiment, the evaporative cooling may further include a fan for drawing in the process air into the dry channel. In an embodiment, the evaporative cooling system may further include at least one fan for drawing in process air into the wet channels.

- 25 The fan may adjust the airflow speed to ensure smooth airflow and maintain cooling efficiency.

In an embodiment, less than 40% of the product air stream may enter the downstream wet channel. In an embodiment, 10 to 15% of the product air stream may enter the downstream wet channel.

In a conventional M-cooler, 40 to 50% of the product air stream may enter the wet channel.

- 5 In the present invention, less product air may be needed, thus improving cooling capacity and energy efficiency. Further reducing the portion of product air stream to 10-15% may enable a marked improvement in these two parameters.

- 10 In an embodiment, a first wet channel may cool the process air close to wet-bulb temperature, and subsequently a second wet channel adjacent to the first wet channel may cool the process air to close to dew-point temperature. Cooling the process air in stages may increase the cooling capacity and energy efficiency of the system.

In an embodiment, at least one additional dry channel may be arranged parallel to the dry channel and in heat transfer communication with the wet channels.

- 15 A portion of the product air from the additional dry channel may be diverted to the wet channel, thus further increasing the cooling capacity and efficiency.

This may ensure smooth airflow, minimises turbulence and mixing of different airs in the dry channels, thus ensuring high cooling capacity and energy efficiency.

In an embodiment, each wet channel may comprise a divider arranged to separate the process air from the portion of the product air from a dry channel.

- 20 The wet channel may contain a subset of channels to separate the air at different temperatures to improve airflow and enhance cooling capacity, since pre-cooled product air does not mix with the process air.

In an embodiment, the dry channels may be arranged to eliminate mass transfer between channels.

- 25 This may increase cooling capacity and efficiency.

In an embodiment, the divider may be adjustable to modulate the portion of the product air stream from the dry channels to the wet channels.

This portion may be adjusted to the application to optimum operation efficiency, and enable user-friendliness.

In an embodiment, the evaporative cooling system may further comprise a plurality of fans to move the air streams in the dry channels.

- 5 The fan may adjust the airflow speed to ensure smooth airflow and maintain cooling efficiency.

In an embodiment, the evaporative cooling system may further comprise at least one container to store and supply a heat transfer fluid to the wet channels.

- 10 An in-built heat transfer fluid may maintain that humidity in the wet channels in a compact system.

Brief Description of the Figures

- It will be convenient to further describe the present invention with respect to the accompanying drawings that illustrate possible arrangements of the invention. Other
15 arrangements of the invention are possible and consequently, the particularity of the accompanying drawings is not to be understood as superseding the generality of the preceding description of the invention.

- Figure 1** shows schematic diagrams of the heat exchanger arrangements and psychrometric charts of (a) a direct evaporative cooler, (b) an indirect evaporative cooler, (c) a dew-point
20 evaporative cooler (so-called M-cycle cooler).

Figure 2A shows the schematic diagram of the heat exchanger arrangement and psychrometric chart of a new dew-point evaporative cooler in this invention.

- Figure 2B** shows a schematic diagram of a “one-to-many” heat exchange arrangement. Although only 3 wet channels are shown in this diagram, it will be appreciated that it is
25 representative of any plurality of wet channels.

Figure 3 are perspective drawings of an evaporative cooler of the present invention. The drawings show heat exchange and air flows in (a) dry channels and (b) wet channels of the new dew-point cooler in this invention

Figure 4 shows graphs of performance comparison of the new two-cooling-stage dew-point cooling mode and the conventional M-cycle cooling mode with the same heat exchange shown in Figure 3, in terms of product air temperature, cooling capacity, and energy efficiency versus the working ratio. The values were obtained for a pair of a wet and a dry channels with a channel length of 20 cm, channel height of 20 cm, and a channel depth of 2 mm. Air speeds in wet channels and dry channels are 1 m/s and 1.5 m/s, respectively. The input air's temperature and humidity ratio are 32°C and 22 g/kg dry air, respectively.

Figure 5A is a perspective view of the main components of a compact two-cooling-stage dew-point cooler.

Figure 5B is a sectional view of the working air flow in wet channels of the cooler.

Figure 5C is a sectional view of the process air in a dry channel of the cooler.

Figure 5D is a cross-sectional view of dry and wet channels of the cooler.

Figure 5E is a sectional view of the liquid water spreading in the wet channels.

Figure 6A shows perspective views of the main component of a compact two-cooling-stage dew-point cooler with horizontal working airflow.

Figure 6B shows perspective views of the exterior of a compact two-cooling-stage dew-point cooler with horizontal working airflow.

Figure 6C is a top view of a compact two-cooling-stage dew-point cooler with horizontal working airflow.

Detailed Description of the Invention

Operating principles of conventional evaporative coolers

In direct evaporative coolers, water 100 and process air stream 101 are in direct contact as described in Figure 1A. The evaporation of water takes place and cools the air. The decrease

in the product air 102 temperature is compromised with the increase in its specific humidity. As shown in the psychrometric chart, the air's enthalpy is constant during the cooling process.

In indirect evaporative coolers, the process air 103 and water 104 are separated with a separator 105 in two channels, wet 106 and dry 107 channels, as described in Figure 1B. The separator 105 enables heat transfer but does not enable mass transfer between the two channels. In the wet channel 106, a working air 108 is used to drive the evaporation. While the process air 103 flows through the dry channel 107. The evaporation of water absorbs heat from both working air and the process air. As the result, the process air 103 is cooled without any change in its humidity. This is a distinct advantage over direct evaporative coolers. In these indirect evaporative coolers, the cooling temperature is limited by the working air's 108 wet-bulb temperature. In other words, the product air's 109 temperature will never be lower than the working air's 108 wet-bulb temperature, as shown in the psychrometric chart. Therefore, this kind of indirect evaporative cooler is classified as a wet-bulb evaporative cooler.

Later, web-bulb evaporative coolers evolved as shown in Figure 1C. In dew-point evaporative coolers, a part of the product air 110 which has been cooled in dry channels 111 is diverted to the wet channels 112 to work as the working air 113. Because the working air is cooled before contacting with water, its cooling potential becomes higher. Therefore, this cooler can achieve product air's 110 temperatures which are even lower than wet-bulb temperature and approaching the dew-point temperature of the process air 114, as shown in the corresponding psychrometric chart in Figure 1C. This arrangement is known as the M-cycle cooling technology.

However, M-cycle coolers have an intrinsic problem in their working mechanism. A significant part of product air 113 is diverted to the wet channels. The working ratio is the volume ratio of the product air that is diverted to wet channels 113 to the total product air 110. In M-cycle evaporative coolers shown in Figure 1C, the lower the product air's temperature becomes, the higher the working ratio must be. In normal working condition, an M-cycle cooler requires 40-50% of the product air to be the working air. This results in the reduction of product air volume to the user as well as the decrease in the overall cooling capacity of the cooler. Additionally, high energy is consumed to drive high working air 113 flowrates in wet channels 112. Therefore, the conventional M-cycle dew-point evaporative coolers have low energy efficiency.

Operating principles of the present invention

According to the present invention, the operating principle of one embodiment is shown in Figure 2A. The process air 200 flows through the dry channel 201 and undergoes two cooling stages as shown in Figure 2A. It is firstly cooled in an indirect wet-bulb evaporative cooling stage 202 to reach a temperature close to the wet-bulb temperature. A working air 203a from an ambient source is introduced into the first stage's wet channel 204a to drive the water evaporation for the cooling process, and is released 207 to the surrounding air. After that, the process air is further cooled in a second cooling stage 205 to reach a temperature close to the dew-point temperature. The working air 203b flowing through wet channels 204b of this second cooling stage is a part of the product air 206. The working air then exits 208 the wet channel. As the process air 200 is significantly cooled in the first stage, the required portion 203b of the product air 206 that is diverted to wet channels 204b is significantly reduced. This results in high cooling capacity and high energy efficiency of the cooler. The changes in air conditions are shown in the corresponding psychrometric chart.

The principle includes the concept of "one-to-many", in that a dry channel may be in heat transfer communication with several wet channels, with various combinations of the wet channels receiving ambient sourced working air and/or receiving at least a portion of process air from an upstream wet channel (Figure 2B). In Figure 2B, the product air 203b enters the wet channel 204b to cool the process air 200 in a first cooling stage 205. A working air 203a1 from an ambient source enters the wet channel 204a1 to cool the process air 200 in a second cooling stage 202, before exiting 2071. Next, another working air 203a2 enters the wet channel 204a2 to cool the process air in a third cooling stage 209, before exiting 2072. The working air 2071 and 2072 may be expelled air that is expelled into the ambient environment.

Therefore, this cooling mechanism may be extended to more than two cooling stages. Each cooling stage may use a different working air. A small portion of product air is used as the working air of the last cooling stage.

The present invention

The heat exchanger, as shown in Figure 3, shows a dew-point evaporative cooler according to a further embodiment of the present invention, having a stack of wet channels 300a, 300b and dry channels 301. Each channel is confined by separating walls 302 and air guides 303. Every dry channel is sandwiched between two adjacent wet channels and vice versa. The separating

walls between adjacent dry and wet channels enable heat transfer but do not enable mass transfer between the two channels. Process air 304 flows through dry channels 301, where it is in direct contact with the dry separating wall surfaces 305 of these channels, and so providing heat transfer communication. To facilitate the two cooling stages, the wet channels
5 are divided into two parts 300a and 300b that enable two working airs 306a and 306b to flow through separately. The working airs 306a and 306b directly contact with wet separating wall surface 307 to drive the evaporation for the cooling process. The first working air 303a, which can be from ambient or other sources, flows through the first part 300a of the wet channels. The second working air 303b, which is extracted from the product air stream 308,
10 flows through the other part 300b of the wet channels 309 arranged in series. The wet channels may cool the working air in graduated stages, one at a different temperature. The temperature difference within each wet channel is reduced, thus resulting in higher homogenous, less turbulence, and higher cooling efficiency.

It is noteworthy that if the product air 304 is diverted to flow through both parts 300a and
15 300b of the wet channels, the cooler becomes a conventional M-cycle cooler. Performance analysis has been carried out when the cooler operates in the conventional M-cycle cooler mode and the new two-cooling-stage dew-point cooler mode. As shown in the comparisons in Figure 4, the new two-cooling-stage dew-point cooler mode has a smaller optimal working ratio than the conventional M-cycle cooler mode. At their optimal working ratios, the new
20 two-cooling-stage dew-point cooler mode achieves lower product air temperature, higher cooling capacity, and higher energy efficiency.

This embodiment of the heat exchanger may be extended to facilitate more than two cooling stages. Each cooling stage may use a different working air. The working air of the last cooling stage is a small portion of the product air. Additionally, this heat exchanger may be
25 modified to facilitate different water supply mechanisms and directions. For example, water can be supplied into the wet channels bottom-up, top-down, or horizontally.

The dew-point cooler

In a further embodiment, Figures 5A to 5E show a cooler adopting a cooling mechanism and air flow configuration to that shown in Figures 2 and 3. This cooler comprises one or more
30 heat exchangers 500 that are stacks of wet 501a, 501b and dry 502 channels following the structure and air flows configuration shown in Figures 2 and 3. This cooler comprises the following other components:

- One or more air blowers 503a, 503b to push or pull the process airs 504 and working airs 505a, 505b through the dry 502 and wet channels 501a, 501b, respectively, of its heat exchanger
- One or more water containers 506 to store and supply water to the wet channels.
- 5 • One or more air guide 507 to divert and adjust a portion 505b of product air 508 to the wet channels.
- A casing and support structure 509 which
 - Provides the mechanical strength and support for other components
 - Protects the system
 - 10 - Guides the air flows in the correct directions
 - Prevents undesirable air leak or bypassing the heat exchanger
 - Has openings for input process air 504, input working air 505a, output product air 508, and output exhaust air 510.

This cooler may include a power supply, air louvers 602, air filters, handles, wheels 603,
 15 electrical controllers 604, indicator lights, supporting frame 605, top cover 606, etc.

This cooler can be modified to facilitate multiple cooling stages, different airflow directions, and different water supply mechanisms and directions. For example, a dew-point cooler with horizontal working airflow is shown in Figures 6A to 6C.

Claims

1. An evaporative cooling system comprising:
a dry channel arranged to receive a process air stream and vent a product air stream;
5 and
a plurality of wet channels in a heat transfer communication with the dry channel, in which the wet channels are arranged to cool the dry channel through an evaporative process;
10 wherein a portion of the product air from the dry channel is received as a process air stream by a first of the wet channels.
2. The evaporative cooling system according to claim 1, wherein the dry channel is divided into a first stage, in a heat transfer communication with a subsequent wet channel, and a second stage in a heat transfer communication with the first wet
15 channel.
3. The evaporative cooling system according to claim 2, wherein the subsequent wet channel is arranged to receive a working air from an ambient source.
20
4. The evaporative cooling system according to claim 1, wherein the plurality of wet channels are in series, such that a portion of process air entering a downstream wet channel is received from a product air stream from an upstream wet channel.
- 25 5. The evaporative cooling system according to any one of claims 1 to 4, wherein air streams in the plurality of wet channels are arranged along a path at an angle to the air stream path of the dry channel.
6. The evaporative cooling system according to claim 5, wherein the angle is 90°.
30
7. The evaporative cooling system according to any one of claims 1 to 6, wherein the dry channel includes walls on opposed sides of the channel, and said wet channels in contact with both of said walls.

8. The evaporative cooling system according to any one of claims 1 to 7, further including a fan for drawing in the process air into the dry channel.
- 5 9. The evaporative cooling system according to any one of claims 1 to 8, further including at least one fan for drawing in process air into the wet channels.
- 10 10. The evaporative cooling system according to any one of claims 4 to 9, wherein less than 40% of the product air stream enters the downstream wet channel.
- 11 11. The evaporative cooling system according to claim 10, wherein 10 to 15% of the product air stream enters the downstream wet channel.
- 12 12. The evaporative cooling system according to any one of claims 4 to 11, wherein the first wet channel cools the process air close to wet-bulb temperature, and subsequently a second wet channel adjacent to the first wet channel cools the process air to close to dew-point temperature.
- 15 13. The evaporative cooling system according to any one of claims 1 to 12, further comprising at least one additional dry channel arranged parallel to the dry channel and in heat transfer communication with the wet channels.
- 20 14. The evaporative cooling system according to any one of claims 5 to 13, wherein each wet channel comprises a divider arranged to separate the process air from the portion of the product air from a dry channel.
- 25 15. The evaporative cooling system according to claim 13 or 14, wherein the dry channels are arranged to eliminate mass transfer between channels.
- 30 16. The evaporative cooling system according to claim 14 or 15, wherein the divider is adjustable to modulate the portion of the product air stream from the dry channels to the wet channels.
- 35 17. The evaporative cooling system according to claim 15 or 16, further comprising a plurality of fans to move the air streams in the dry channels.
- 40 18. The evaporative cooling system according to any one of claims 15 to 17, further comprising at least one container to store and supply a heat transfer fluid to the wet channels.