COUNTER-FLOW INDIRECT DEW-POINT EVAPORATIVE COOLING METHOD AND APPARATUS

TECHNICAL FIELD

This invention relates to a method and apparatus for indirectly cooling an air stream from its ambient temperature to a temperature closed to its dew-point.

BACKGROUND

Air conditioners have been widely employed for controlling the temperature and the humidity of the air to provide thermal comfort as well as a hospitable environment in commercial buildings, residential houses, data centers, hospitals, schools, industrial houses, supermarkets, transportation means, etc. As the population grows, incomes rise around the world and global temperatures go up, demand for air conditioners is increasing. However, the rise in conventional air conditioning is driving up climate change.

To reduce the energy consumption and greenhouse gas emission of the conventional air-conditioning systems, several alternative technologies have been studied, such as absorption/adsorption chillers and evaporative coolers, have been proposed. Among these approaches, evaporative coolers have a lot of advantages and merits, including high 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 are classified into direct evaporative coolers and indirect evaporative coolers.

In the direct evaporative coolers, the water and process air are in direct contact. The evaporation of water takes place and cools the air. However, the decrease in the process air temperature is compromised with the increase in its humidity ratio.

In indirect evaporative coolers, the process air and water are separated by using a separator that enables heat transfer but does not enable the mass transfer. The process air is cooled without any change in its humidity ratio. This is a distinctive advantage over the direct evaporative coolers. However, the temperature of the product air of these coolers is thermodynamically limited to be lower than the working air’s wet-bulb temperature. Therefore, this kind of cooler is classified as an indirect wet-bulb evaporative cooler.

Later, the indirect web-bulb evaporative cooler was improved to become an indirect dew-point evaporative cooler by Dr. Maisotsenko. In an indirect dew-point evaporative cooler, the process air 100 is cooled in the dry channels 101, as shown in Figure 1 (a). A part of the product air 102 which has been cooled in the dry channels 101 is diverted to the wet channels 103 to be the working air 104 to drive the water evaporation. Because the working air 104 is cooled

before contacting with water, the cooling potential becomes higher. Therefore, the working air 104 in the wet channels 103 can reach the dew-point temperature and it can cool the process air 100 in the dry channel 101 to a temperature below the wet-bulb temperature, as shown in the psychrometric chart in Figure 1 (b). The technology was then adeptly known as the M-cycle cooling technology.

The most well-known M-cycle indirect evaporative cooler is the Coolerado cooler, which is based on cross-flow configuration 200 as shown in Figure 2 (a). The process air 201 flows through the dry channel 202. Some parts of process air are diverted via the series of through-holes 203 to the wet channel 204 to become the working air. Process air and working air are in a cross-flow configuration. The exhausted air 205 and product air 206 are going out at the ends of the wet and dry channels, respectively. With this design, it has higher cooling effectiveness than that of the indirect we-bulb evaporative cooler. However, it is still facing some shortcomings: (1) the product air is not fully cooled as a high proportion of the process air is gradually diverted early into the wet channels, and (2) cross-flow pattern leads to low effectiveness of the heat exchanger.

To resolve the problems caused by the cross-flow configuration, indirect dew-point evaporative coolers with counter-flow configuration (Figure 2 (b)) have been proposed and studied. The process air 208 flows through the dry channel 209 and is diverted to the working air 211 at the end of the dry channel 210. The process airflow and working airflow are in counter-flow configuration. The exhaust air 212 and product air 213 are then leaving the heat exchanger. These counter-flow indirect dew-point evaporative coolers have a higher cooling capacity and higher dew-point effectiveness than the cross-flow ones.

However, these counter-flow and cross-flow indirect dew-point evaporative coolers shown in Figure 2 have an intrinsic problem. That is the product air is abruptly turn from the dry channel to the wet channel. Because of it, the working air is uneven and the pressure drop between dry and wet channels is high. As a result, more energy is required to drive the airflows. Therefore, the cooling performance and energy efficiency of these cooler are low.

SUMMARY

This invention entails a new counter-flow indirect dew-point evaporative cooler, which eliminates the turn of the product air when it flows from the dry channels to the wet channels. This enables the cooler to have more even airflows and use less energy to drive the airflows in its channels. This is a great evolution of the indirect dew-point evaporative cooler in terms of better cooling performance, better energy efficiency, easier controlling, and operation.

New counter-flow indirect dew-point evaporative cooling mechanism

Technically, the heat exchanger of this cooler consists of two halves which are two identical indirect evaporative coolers 300, 301. The two halve 300, 301 are attached in the way that the dry channels 302 of this half is connected to the wet channels 303 of the other, as shown in Figure 3. The process air 304 enters the cooler at the two ends of the heat exchanger, then flows through the dry channels 302, where it is cooled by the evaporation of water in the adjacent

wet channels. At the end of the dry channels of this half, one part of the cooled air is diverted to exit the heat exchanger to be the product air 305; the rest of the cooled air continues to flow through the wet channels of the other half to be the working air. The exhaust air 306 carrying moisture gets out of the cooler at the end of the wet-channels.

In this way, the direction of the product air is not changed when it enters the wet channels to become the working air. Therefore, the airflows are more even and the pressure drop is much smaller, compared with the conventional M-cycle evaporative cooler shown in Figure 1 (a). As a result, the cooling performance and energy efficiency of this new counter-flow indirect dew-point evaporative cooler are higher.

BRIEF DESCRIPTION OF THE FIGURES

Figure 1: Operating principle of the conventional indirect dew-point evaporative cooler (so-called M-cycle indirect evaporative cooler)

Figure 2: (a) cross-flow and (b) counter-flow configurations of the conventional indirect dew-point evaporative cooler.

Figure 3: Operating principle of the new counter-flow indirect dew-point evaporative cooler

Figure 4: The three- dimensional heat exchanger and flows' configuration of the new counter-flow indirect dew-point evaporative cooler. The views of the process air entering the heat exchanger from (a) left and (b) right ends of the heat exchanger.

Figure 5: A new compact counter-flow indirect dew-point evaporative cooler.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

The following preferred embodiment as exemplified by the drawings is illustrative of the invention and is not intended to limit the invention as encompassed by the claims of the application. The major advantage of the present invention is cooling air by using a simple and compact apparatus that has a high cooling capacity, high cooling effectiveness, and high energy efficiency.

Heat exchanger structure and airflow configuration

The heat exchanger 400, as shown in Figure 4, of this new dew-point evaporative cooler is consisted of two halves 401 and 402. Each half is a stack of dry channels 403 and wet channels 404. Each channel is confined by separating walls 405 and air guides 406. 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. The dry channels of this half are connected to the wet channels of the other half and vice versa, which enables the product air of this half to be the working air of the other half without changing its direction. The airflows in dry and wet channels are in counter-flow

configuration. The process air 407 enters the heat exchanger at its two ends then flows through dry channels 403 where it is in contact with the drywall surfaces 408 of these channels. After leaving the dry channel of this half, one part of this air is diverted to exit the heat exchanger as the product air 409, the rest of the air continues to flow through the working air channels of the other half, where it is in direct contact with the wet wall surfaces 410 of these channels. The exhaust air 411 carrying moisture exits at the end of the wet channels. To maintain surface 410 to be wet, extension 412 of this wall is kept in contact with water.

According to the preferred embodiment above, the heat exchanger is horizontal, the wet and dry channels are vertical, the process air is horizontal, the exhaust and product airs flow from bottom to top. However, the present invention also includes other configurations, in which the heat exchanger, wet and dry channels, the airflows have different directions, provided that they are in the accordance with the cooling principle shown in Figure 3.

The cooler and its operation

A cooler that is developed to realize the cooling mechanism and airflow configuration in Figures 3 and 4, is shown in Figure 5.

This cooler 500 comprises one or more heat exchangers 501 with the structure and airflow configuration shown in Figure 4. This cooler comprises the following other components:

- One or more air blowers 502 to propel the process air 503 to enter the heat exchanger from its two ends;
- One or more water containers 504 to store and supply water to the wet channels.
- A case and support structure 505 which
    - provide mechanical strength and support for other components
    - protects the system
    - guides the air flows in the correct directions
    - prevents undesirable air leak or air bypassing the heat exchanger
    - has openings for input process air 503, output product air 506, and output exhaust air 507.

This cooler may include power supply, air ducts, air louvers, air filters, handles, wheels, electrical controllers, indicators lights, etc.

The invention also includes mechanisms for distributing water into wet channels such as the utilization of the capillary effect to bring water into the layers of hollow materials (such as fabrics, fibers, etc.) on the surface of the separators; using equipment to spray or drip water into wet channels; or producing water droplets to mix into the working air stream.

Although the invention has been described in detail about its preferred embodiment, a person with an average technical knowledge of the field needs to understand that various changes can be made within the scope of the claims.

Advantages of this new counter-flow indirect dew-point evaporative cooler

Because this new counter-flow indirect dew-point evaporative cooler enables the product air to get in the wet channel to be the working air without changing its flow direction, this cooler has below advantages compared with the conventional M-cycle indirect evaporative cooler:

- More even air flows in its channels
- Lower pressure drops in its channels
- Easy controlling the ratio of airflows in the wet and dry channels
- Able to facilitate higher airspeed in its channels
- Higher dew-point cooling effectiveness
- Lower energy consumption and higher energy efficiency

CLAIMS

1. A counter-flow indirect dew-point evaporative cooling mechanism that facilitates a part of the product air to flow from the dry channels to the wet channels without changing its direction.
2. A heat exchanger comprises two identical halve, wherein
    - each half is a stack of dry channels and wet channels;
    - each channel is confined by separating walls and air guides;
    - every dry channel is sandwiched between two adjacent wet channels and vice versa;
    - the separating walls between adjacent dry channels and wet channels enable the heat transfer but do not enable the mass transfer between the two types of channels;
    - separating walls have wet surfaces on the wet channels and dry surface on the dry channels;
    - the two halve are attached in the way that the dry channels of this half are connected to the wet channels of the other;
    - the process air enters the dry channels from the two ends of the heat exchanger;
    - the product air, after leaving the dry channels of this half, flows through the wet channels of the other half without changing its direction.
    - the airs' flows in dry channels and wet channels are in a counter-flow configuration;
3. A cooler comprises one or more heat exchangers according to Claim 2 and the following other components:
    - one or more air blowers to propel the process air through the heat exchanger from its two ends;
    - one or more water containers to store and supply water to the wet channels;
    - a case and support structure to provide the mechanical strength and support for other components, to protect the system, to guide the air flows in the correct directions, to prevent undesirable air leak or air bypassing the heat exchanger, to have openings for the input process air, input water, output product air, and output exhaust air;
    - power supply, air ducts, air louvers, air filters, handles, wheels, electrical controllers, thermal insulators, indicators, lights.