

[54] **EVAPORATIVE COOLING APPARATUS**

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[51] **Int. Cl.**..... **F28d 5/00**

[58] **Field of Search** 62/305, 314; 261/DIG. 11, 261/154, 100, 101, 103

[56] **References Cited**

UNITED STATES PATENTS

2,485,849	10/1949	Simmons.....	62/305
2,570,247	10/1951	Kals	62/305
2,662,741	12/1953	Boyle	62/305

3,010,706	11/1961	McWilliams	261/100
3,113,102	12/1963	Schulze	261/103
3,132,190	5/1964	Engalitcheff.....	62/305
3,346,246	10/1967	Loetel.....	261/103
3,384,994	3/1968	Greer.....	261/112
3,395,900	8/1968	Meek.....	261/29
3,415,502	12/1968	Munters.....	261/112

FOREIGN PATENTS OR APPLICATIONS

203,616	10/1956	Australia.....	261/100
251,600	2/1970	U.S.S.R.....	62/305

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[57] **ABSTRACT**

An evaporative cooling apparatus comprising an outer casing provided with air inlets and an air outlet, cooling units composed of serpentine heat exchanging pipes and disposed for cooling indirectly and continuously a fluid to be cooled, fillers disposed in voids formed between two adjoining stages of the heat exchanging pipes by serpentine configuration of the heat exchanging pipes, a fan mounted to pass air through the cooling units, a liquid distributor for sprinkling a coolant liquid to the cooling units, a basin for receiving the coolant liquid which has been sprinkled from said liquid distributor and flown downwardly through the cooling units, and an eliminator provided to prevent splash liquids formed in the outer casing from dispersing outside the outer casing.

13 Claims, 17 Drawing Figures

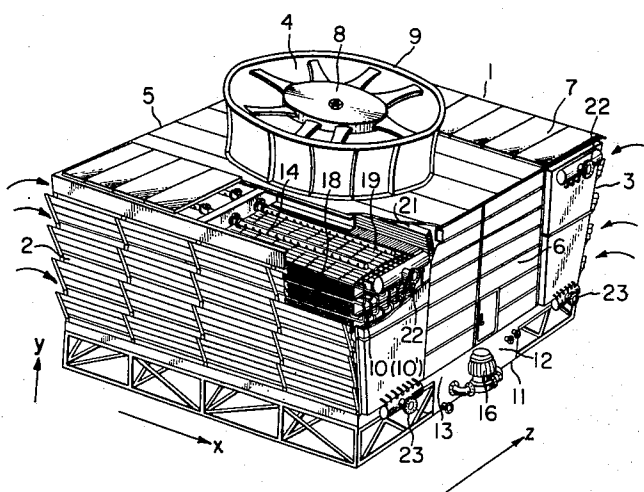


FIG. 1

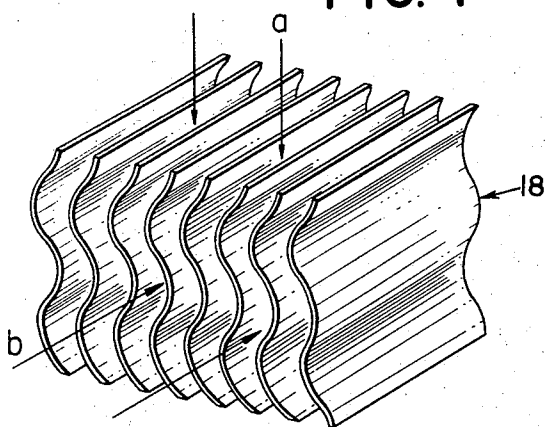


FIG. 3

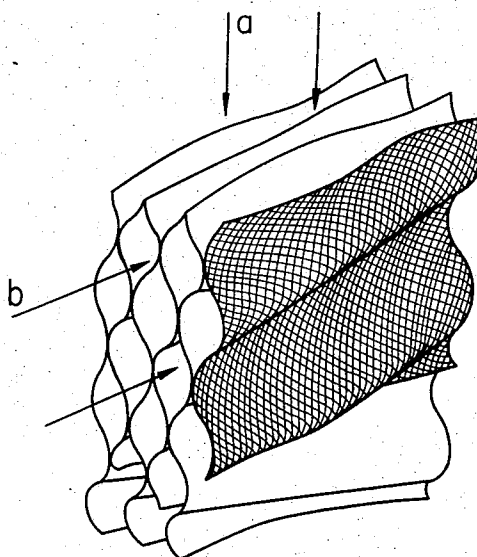


FIG. 2

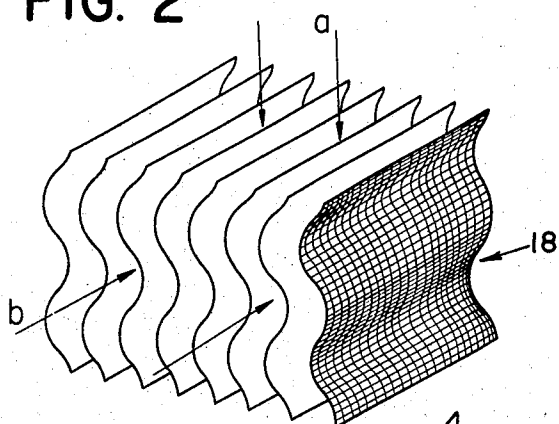


FIG. 4

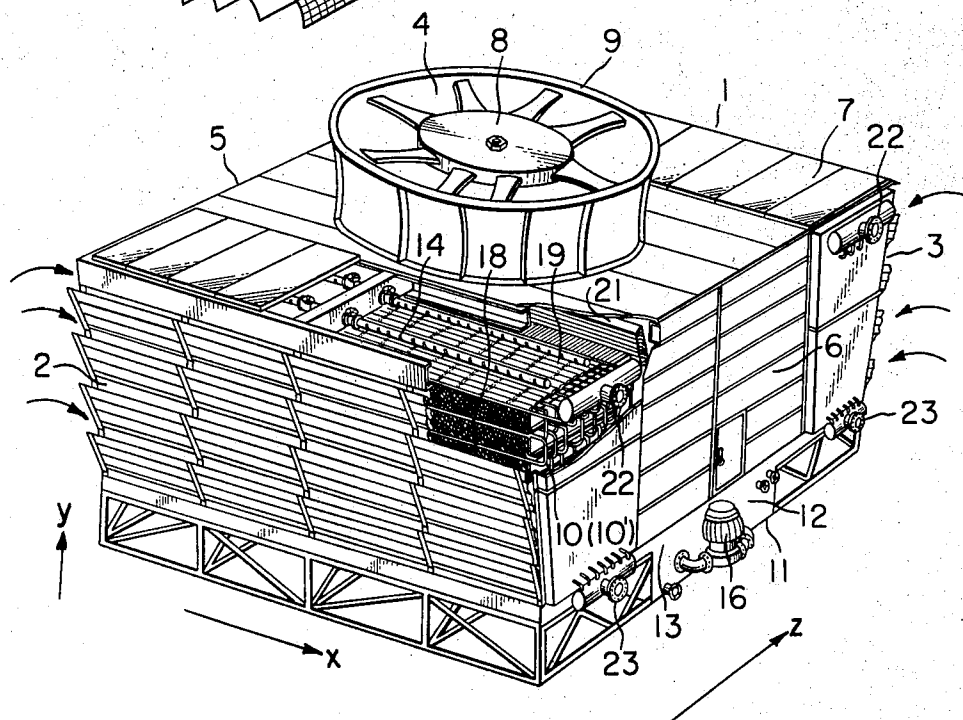


FIG. 5

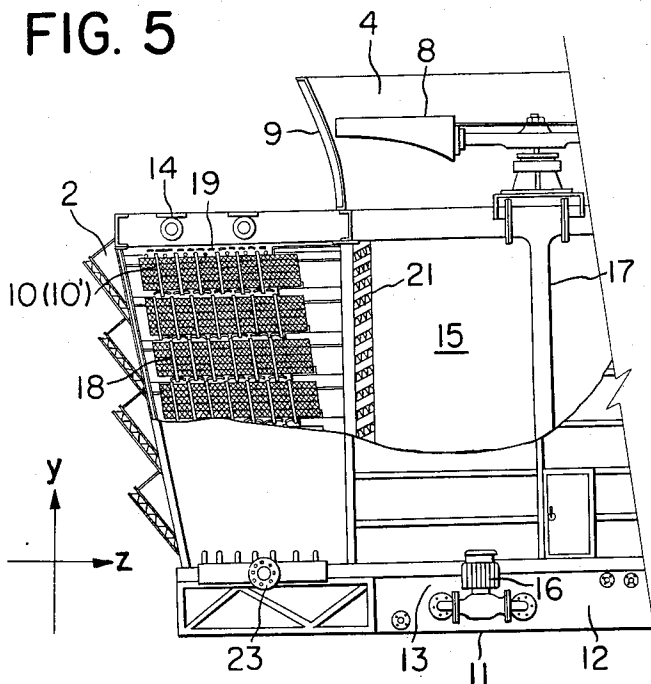


FIG. 7

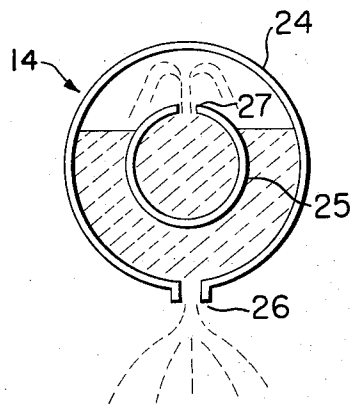


FIG. 6

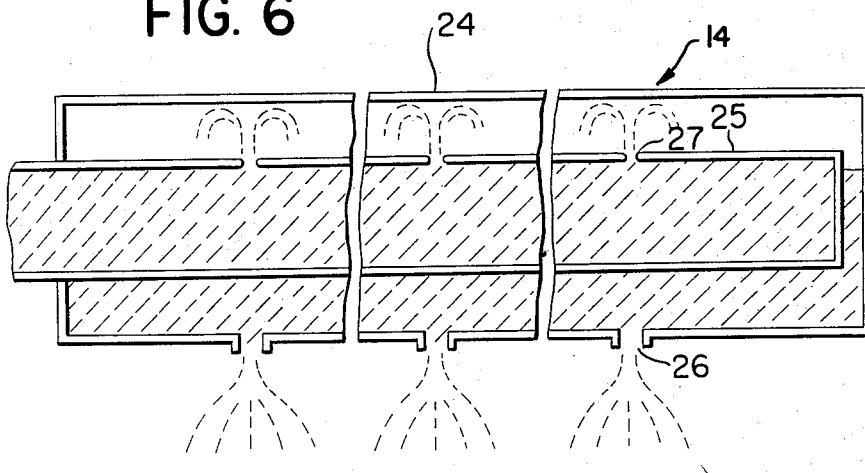


FIG. 8

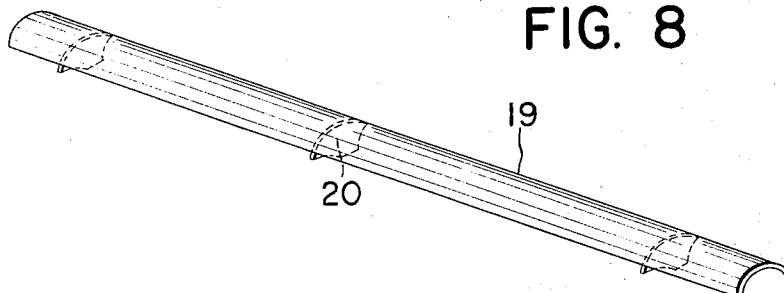


FIG. 9

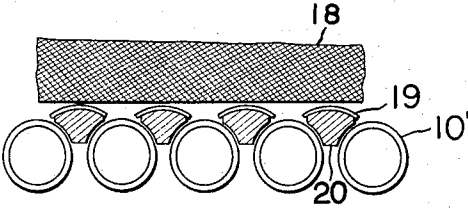


FIG. 10

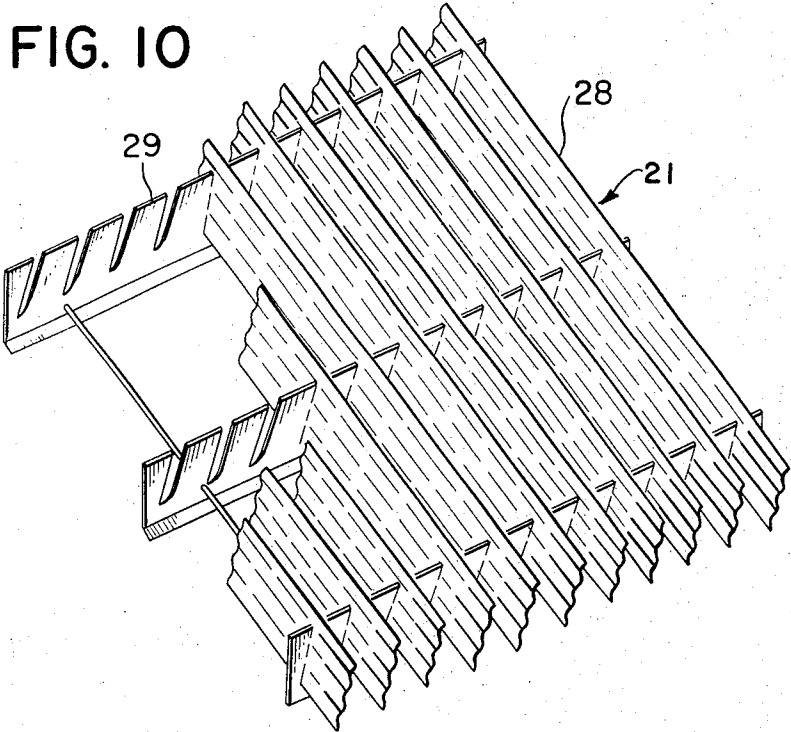


FIG. 11

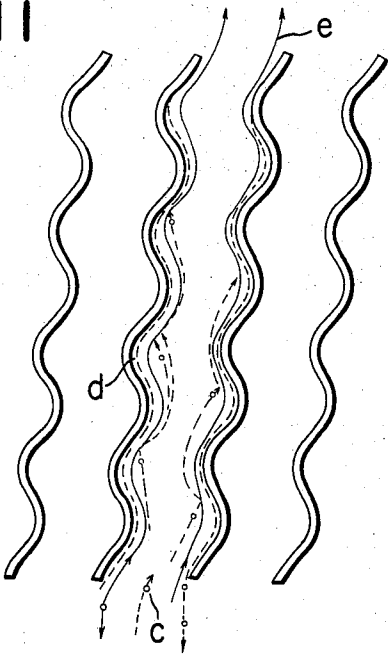


FIG. 12

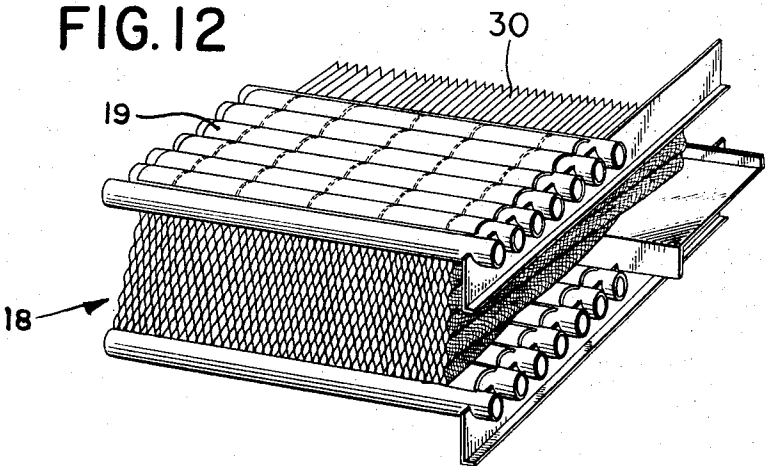


FIG. 13

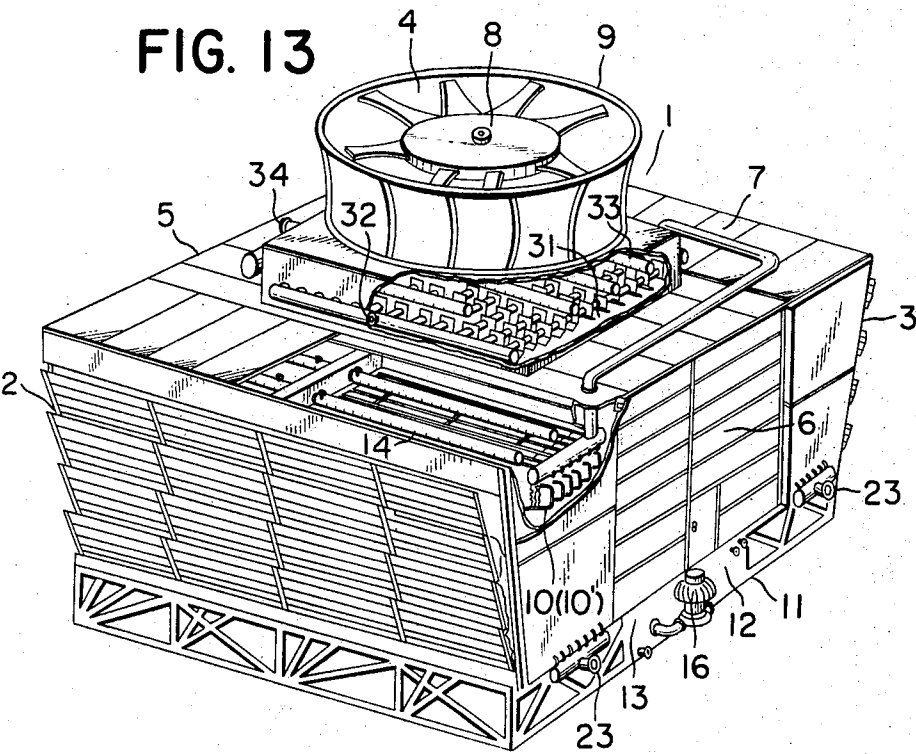


FIG. 14

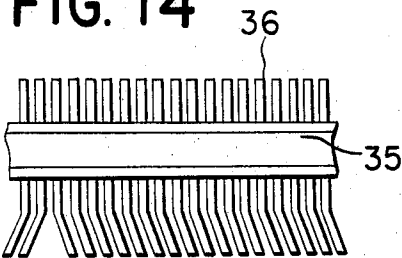


FIG. 15

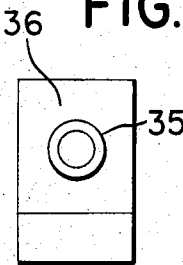


FIG. 16

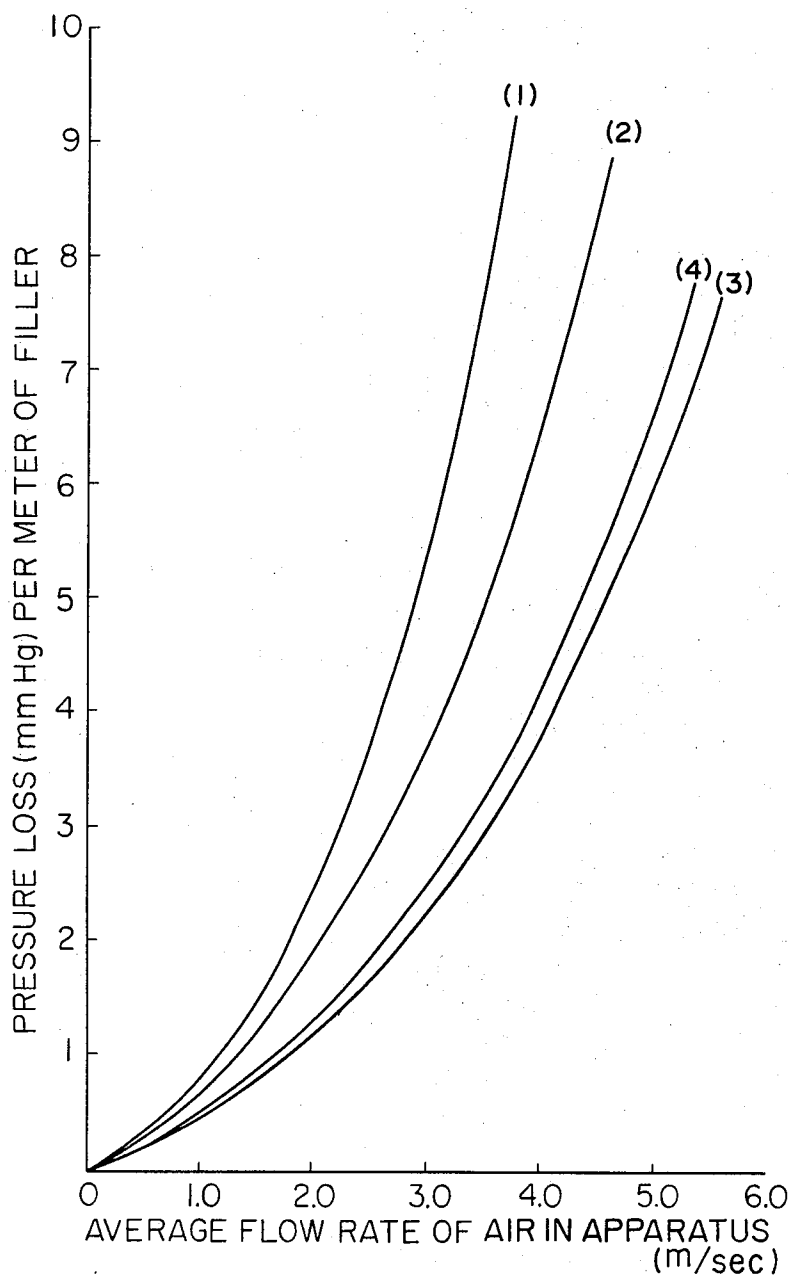
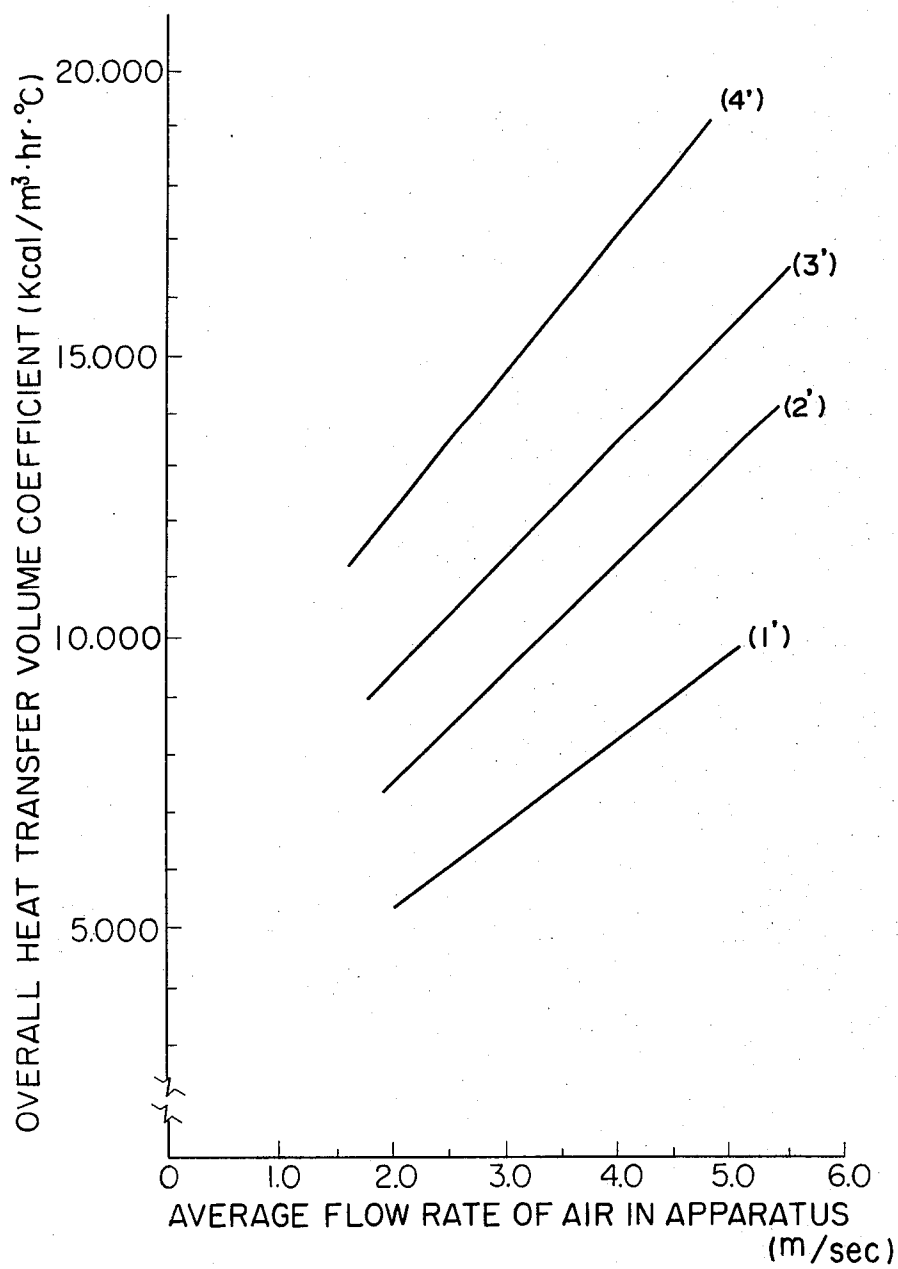


FIG. 17



EVAPORATIVE COOLING APPARATUS

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to improvements in an evaporative cooling apparatus for use in cooling or condensing a fluid to be cooled or condensed, such as a process fluid and a cooling medium fluid.

In general, evaporative cooling apparatuses comprise an outer casing provided with an air inlet and an air outlet, cooling units composed of variform heat exchanging pipes and disposed to cool indirectly a fluid to be cooled, a fan for passing air through said cooling units, a liquid distributor for sprinkling a coolant liquid to the cooling units, a basin for receiving the coolant liquid which has been sprinkled from said liquid distributor and flown downwardly through the cooling units, and an eliminator provided to prevent splash liquids formed in the outer casing from dispersing outside the outer casing. In short, evaporative cooling apparatuses are cooling devices which can accomplish the cooling or condensing of fluids relatively efficiently by utilizing the latent heat of the coolant liquid effectively.

2. Description of the Prior Art

A variety of evaporative cooling apparatuses have heretofore been proposed and disclosed in, for instance, Japanese Utility Model Publication No. 9386/59 and Japanese Patent Publication No. 9093/60. In these conventional evaporative cooling apparatuses, the coolant liquid flows down through the cooling units at a very high speed, and attainment of the important feature of the evaporative cooling apparatus, i.e., the evaporative cooling action by the coolant liquid, is extremely prohibited, resulting in extreme reduction of the efficiency of cooling a fluid to be cooled. As the improvement overcoming the above defect, Japanese Patent Publication No. 1066/67 (U.S. Pat. No. 3,141,308) proposes an evaporative cooling apparatus in which heat exchanging pipes of serpentine form are used and filler assemblies are provided in voids formed between two adjoining stages of heat exchanging pipes by serpentine configuration of the heat exchanging pipes. In this proposal, each of the filler assemblies includes filler slats arranged in a plurality of stages and in a plurality of lines, and frames supporting these filler slats, and these filler assemblies are disposed in voids formed between two adjoining stages of the cooling units so that the coolant liquid falling downwardly from the filler slats of the upper stage is allowed to drop down successively onto the upper part of each filler slat of the next stage, namely the longitudinal direction of the filler slat corresponds to the serpentine direction of the heat exchanging pipe (the direction of the axis x).

SUMMARY OF THE INVENTION

This invention relates to an evaporative cooling apparatus which comprises an outer casing provided with air inlets and an air outlet; cooling units for continuously and indirectly cooling a fluid to be cooled, each of said cooling units including a plurality of heat exchanging pipes of a serpentine configuration meandering in the lateral direction (the direction of the axis x) which extend in the vertical direction (the direction of the axis y) without substantial protrusion outside the outer casing and are disposed in parallel to each other

in the lateral direction (the direction of the axis z) along the air flow, the upper and lower ends of each of said heat exchanging pipes being connected to an inlet and an outlet for a fluid to be cooled, respectively; fillers for mainly accomplishing diffusion of liquid films which are disposed in voids formed between two adjoining stages of the heat exchanging pipes by serpentine configuration of the heat exchanging pipes so that the lengthwise direction of the central face of each segment of the filler corresponds to the lateral direction (the direction of the axis z) rectangular to the serpentine direction (the direction of the axis x) of the heat exchanging pipe of the cooling unit, and the central face in the widthwise direction of the filler segment extends almost vertically without interruption between the lower end of the heat exchanging pipe of one stage and the upper end of the heat exchanging pipe of the next lower stage; a suction blower for passing air through said cooling units; a tubular liquid distributor of a double-tube structure for sprinkling a coolant liquid to said cooling units; semilunar liquid-collecting plates suspended between two adjoining stages of the heat exchanging pipes to collect the coolant liquid flowing downwardly along the fillers on the heat exchanging pipes, each of said semilunar liquid-collecting plates being located so that the lengthwise direction thereof corresponds to the lateral direction (the direction of the axis x) of each stage of the heat exchanging pipes; a basin for receiving the coolant liquid which has been sprinkled from said liquid distributor and flown downwardly through the cooling units; and a wavy plate-like eliminator provided to prevent splash liquids formed in the outer casing from dispersing outside the outer casing.

This invention also relates to an evaporative cooling apparatus of the above structure wherein said fillers are composed of net-like segments and, according to need, the air outlet side end of the filler is extended into the space on the air outlet side so that splash liquids formed in the outer casing are auxiliarily removed by the net of the filler before the splash liquids reach the eliminator.

This invention further relates to an evaporative cooling apparatus of the above structure wherein sea water is used as the coolant liquid and a dry heat exchanger is provided at the air outlet to remove fine droplet splashes of sea water leaking out of the eliminator, especially salt components contained therein.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an explanatory view illustrating a part of the filler of this invention composed of wavy plate-like segments.

FIG. 2 is an explanatory view illustrating a part of the filler of this invention composed of wavy net-like segments.

FIG. 3 is an explanatory view illustrating a part of the filler of this invention composed of net-like segments of an inclined wavy configuration.

In FIGS. 1 to 3, the arrow a indicates the direction of falling of the coolant liquid, and the arrow b indicates the direction of the flow of air.

FIG. 4 is a partially cut-out view illustrating one embodiment of the evaporative cooling apparatus 1 of this invention, and FIG. 5 is a view showing the longitudinal section of the evaporating cooling apparatus 1 illustrated in FIG. 4, the apparatus having air inlets 2 and

3, an air outlet 4, an outer casing 5, a side wall 6, a top wall 7, a suction blower 8, a cover 9 for the suction blower, assemblies 10 of serpentine pipes, an individual pipe 10, a bottom wall, a side wall 12, an open liquid collector 13, a liquid distributor having a double-tube structure, an open space 15, a pump 16, a conduit 17 for feeding the coolant liquid to the liquid distributor from the liquid collector, a filler 18 composed of net-like segments of an inclined wavy configuration, a semilunar liquid-collecting plate 19, a plate-like eliminator 21 of a wavy configuration, an inlet 22 for a fluid to be cooled and an outlet 23 for a fluid to be cooled, respectively.

FIGS. 6 and 7 are explanatory views showing the longitudinal section of the liquid distributor 14 having a double-tube structure, in which numerals 24 and 25 indicate an outer tube and a liquid feed pipe, respectively and numerals 26 and 27 indicate openings.

FIG. 8 is a perspective view of the semilunar liquid-collecting plate 19 of this invention and FIG. 9 is a sectional view illustrating the arrangement of the semilunar liquid-collecting plates 19, wherein numeral 20 indicates a leg of the semilunar liquid-collecting plate 19.

FIG. 10 is a view illustrating a part of the plate-like eliminator 21 of this invention, and FIG. 11 is a view illustrating a part of a vane plate 28 of the eliminator 22, wherein numeral 29 indicates a supporting member for the vane plate 28, and *c*, *d* and *e* indicate liquid drops, a liquid film and the direction of the flow of air, respectively.

FIG. 12 is a view illustrating an example of the arrangement of filler segments 18 of this invention shown in FIG. 3, wherein numeral 30 indicates a portion of the filler extended into the space on the air outlet side according to one feature of this invention.

FIG. 13 is a partially cut-out view illustrating another embodiment of the evaporative cooling apparatus 1 of this invention in which a dry heat exchanger 31 is provided.

FIGS. 14 and 15 are views illustrating the sections of the heat exchanging pipe constituting the dry heat exchanger 31, wherein numerals 32, 33, 34, 35 and 36 respectively indicate an inlet for a fluid to be cooled, a liquid sprayer for spraying a liquid for removing scales, an inlet for the scale-removing liquid, a tube and a fin.

FIG. 16 is a graph illustrating the relation between the average flow rate (m/sec) of air in the apparatus and the pressure loss (mm Ag) per meter of the filler, wherein (1) is a curve obtained when conventional fillers are provided, (2) is a curve obtained when fillers of this invention composed of wavy plate-like segments are provided, (3) is a curve obtained when fillers of this invention composed of net-like segments of an inclined wavy configuration are provided, and (4) is a curve obtained when fillers of this invention composed of net-like segments of a horizontal wavy configuration are employed.

FIG. 17 is a graph illustrating the relation between the average flow rate (m/sec) of air in the apparatus and the overall heat transfer volume coefficient (Kcal/m³·hr·°C), wherein (1') is a curve obtained when conventional fillers are provided, (2') is a curve obtained when fillers of this invention composed of wavy plate-like segments are provided, (3') is a curve obtained when fillers of this invention composed of net-

like segments of an inclined wavy configuration are provided, and (4') is a curve obtained when fillers of this invention composed of net-like segments of a horizontal wavy configuration are employed.

DETAILED DESCRIPTION OF THE INVENTION

The fundamental factors for facilitating the evaporation of a coolant liquid (hereinafter referred to as "water" because water is usually employed as the coolant liquid) by provision of fillers such as fill members disclosed in Japanese Patent Publication No. 1066/67 (U.S. Pat. No. 3,141,308) are deemed to reside in increase of the surface area of water per unit volume thereof and also in increase of the amount of air passing while having a contact with water per unit volume of water per unit time. However, in the background of the proposal of said Japanese Patent Publication there lies an intention to effect the evaporative cooling while forming in the air as many water drops as possible by provision of such fill members and thereby increasing the contact area between air and water. Indeed, water drops take a spherical form and hence, have a large surface area, and therefore, it seems that the evaporation from such large surface is very effective. However, in case water drops are formed in a vessel of a certain dimension, the resistance to air passing through the vessel becomes great because of the presence of water drops and the contact of air with water drops cannot be maintained for a long period of time, resulting in extreme reduction of heat transfer by evaporation of water drops. Further, the pressure loss of air is not only caused by passage of air through water drops but also increased by use of an eliminator disposed to prevent water drops from dispersing outside the cooling apparatus. Therefore, the total pressure loss becomes considerable and the heat exchange efficiency is further reduced. In other words, in a conventional evaporative cooling apparatus in which fillers are provided mainly for diffusion of water drops, a sufficient consideration is made to satisfy the first condition of the above-mentioned fundamental factors, i.e., increase of the surface area of water per unit volume thereof, but no significant consideration is paid to attainment of the second condition, i.e., increase of the amount of air passing while having a contact with water per unit volume of water per unit time.

In this invention the apparatus is constructed so that both of the above two fundamental conditions can be satisfied as much as possible. Namely, the most characteristic feature of the evaporative cooling apparatus provided by this invention is that fillers are provided mainly for diffusion of water films, whereby the evaporative cooling can be accomplished with a very high efficiency of heat exchange.

More specifically, in accordance with this invention there is provided an evaporative cooling apparatus which comprises an outer casing provided with air inlets and an air outlet; cooling units for continuously and indirectly cooling a fluid to be cooled, each of said cooling units including a plurality of heat exchanging pipes of a serpentine configuration meandering in the lateral direction (the direction of the axis *x*) which extend in the vertical direction (the direction of the axis *y*) without substantial protrusion outside the outer casing and are disposed in parallel to each other in the later direction (the direction of the axis *z*) along the air flow, the upper and lower ends of each of said heat ex-

changing pipes being connected to an inlet and an outlet for a fluid to be cooled, respectively; fillers for mainly accomplishing diffusion of liquid films which are disposed in voids formed between two adjoining stages of the heat exchanging pipes by serpentine configuration of the heat exchanging pipes so that the lengthwise direction of the central face of each segment of the filler corresponds to the lateral direction (the direction of the axis z) rectangular to the serpentine direction (the direction of the axis x) of the heat exchanging pipe of the cooling unit and the central face in the widthwise direction of the filler segment extends almost vertically without interruption between the lower end of the heat exchanging pipe of one stage and the upper end of the heat exchanging pipe of the next lower stage; a fan for passing air through said cooling units; a liquid distributor for sprinkling a coolant liquid to said cooling units; a basin for receiving the coolant liquid which has been sprinkled from said liquid distributor and flown downwardly through the cooling units; and an eliminator provided to prevent splash liquids formed in the outer casing from dispersing outside the outer casing.

As the filler segment for mainly accomplishing diffusion of water films to be used in this invention, there may be exemplified plate-like segments of a wavy configuration such as illustrated in FIG. 1, and net-like segments of a wavy configuration such as illustrated in FIGS. 2 and 3, but it is not limited to examples illustrated in these FIGS. In short, there may be used any of fillers for mainly accomplishing diffusion of water films, if they are disposed in voids formed between two adjoining stages of the heat exchanging pipes by serpentine configuration of the heat exchanging pipes so that the lengthwise direction of the central face of each segment of the filler corresponds to the lateral direction (the direction of the axis z) rectangular to the serpentine direction (the direction of the axis x) of the heat exchanging pipe of the cooling unit and the central face in the widthwise direction of the filler segment extends almost vertically without interruption between the lower end of the heat exchanging pipe of one stage and the upper end of the heat exchanging pipe of the next lower stage.

In case fillers of this invention are disposed so that, as illustrated in Japanese Patent Publication No. 1066/67 (U.S. Pat. No. 3,141,308), the central face in the lengthwise direction of each segment extends in the serpentine direction (the direction of the axis x) of the heat exchanging pipe, the pressure loss of air is extreme and the apparatus cannot be used practically.

In the case of a wavy plate-like filler segment such as shown in FIG. 1, projections or convexities and concavities may be formed on the surface for attaining a good mixing of the film stream flowing on the surface of the filler segment. Further, this plate-like filler segment may be water-permeable. The wavy configuration referred to herein is not limited to smooth one such as illustrated in FIG. 1 but includes those having concavities and convexities thereon.

Net-like filler segments of a wavy configuration illustrated in FIG. 2 are disposed in parallel to each other so that crests and troughs of every two adjoining segments confront each other and a prescribed distance, for instance, 1.5 - 2 cm, is formed between the adjoining segments, and they are supported in this state by supporting members. In FIG. 3, one of every two ad-

joining net-like filler segments of a wavy configuration is inclined at an angle of $\tan^{-1} 1.0^\circ$ to $\tan^{-1} 1.5^\circ$ to the horizontal direction so that wave crests of the two adjoining segments cross each other, and in this state they are supported by supporting members.

In FIGS. 1 to 3, the arrow a indicates the direction of falling of the coolant liquid, and the arrow b indicates the direction of the passage of air.

In net-like filler segments illustrated in FIGS. 2 and 3 both the front and back surfaces can pass water therethrough, and therefore, the mixing of the film flows can be conducted very effectively. Further, the surface area of the coolant liquid having a contact with air is very great. Accordingly, the evaporative cooling action of the coolant liquid can be greatly promoted, with the result that a prominent effect of rapidly cooling a fluid to be cooled which is passing through the heat exchanging pipes can be attained.

In the net-like filler segment to be used in this invention, the mesh size or configuration of the net is not particularly critical, and the mesh size is suitably determined depending on the configuration of the net, the properties of the coolant liquid and other factors.

In this invention, various metallic substances may be used as fillers, but is preferable to employ fillers composed of synthetic resins such as polyvinyl chloride, polyethylene and polypropylene.

In accordance with another feature of this invention, there is provided an evaporative cooling apparatus of the above-mentioned structure wherein a suction blower is provided as the fan for feeding air to the cooling units.

In case a fan of the forced draft type is employed, as illustrated in Japanese Patent Publication No. 1066/67 (U.S. Pat. No. 3,141,308), it is necessary to provide a rectifying plate for feeding a uniform stream of air to the cooling units, with the result that the pressure loss of air is caused by provision of such rectifying plate and a great quantity of power is consumed for forming such uniform stream of air. In contrast, when a suction blower such as designated as 8 in FIG. 4 is provided, a uniform stream of air can be obtained without use of a rectifying plate. The effect attained by provision of such suction blower is multiplied in an evaporative cooling apparatus of a great dimension.

In still another feature of this invention, there is provided an evaporative cooling apparatus of the above-mentioned structure, wherein a cylindrical liquid distributor of a double-tube structure, the section of which is shown in FIGS. 6 and 7, is provided as the liquid distributor for sprinkling a coolant liquid to the cooling units.

This tubular distributor has a double-tube structure consisting of an outer tube 24, both ends of which are closed, and a liquid feed tube 25 inserted through the outer tube 24, one end of said liquid feed tube 25 being closed. Liquid outlets 26 are perforated at suitable intervals on the lower portion of said outer tube, and liquid overflowing openings 27 are perforated on the liquid feed tube. In case a conventional cylindrical liquid distributor (single-tube structure) is employed, uniform pressure distribution cannot be obtained in the coolant liquid. More specifically, the pressure of the coolant liquid differs between the inlet portion of the cylinder and the terminal portion of the cylinder. Therefore, the amount of the coolant liquid sprayed on the unit area of the cooling unit is not uniform, and

hence, it is impossible to obtain an efficient contact between the coolant liquid and air on the filler surface. In contrast, when the liquid distributor of a double-tube structure is mounted according to this invention, the coolant liquid overflowed from the openings 26 is diffused in the outer tube 24 and sprayed from the openings 27 of the outer tube. Thus, the spraying can be accomplished without substantially undergoing bad influences by such non-uniformity of extrusion pressure as mentioned above. As a result, the coolant liquid is uniformly distributed and sprayed.

In a still further feature of this invention, there is provided an evaporative cooling apparatus of the above-mentioned structure, wherein semilunar liquid-collecting plates such as designated as 19 in FIG. 5 and shown in FIGS. 8 and 9 are provided in the state suspended between two adjoining stages of the heat exchanging pipes, each of said semilunar liquid-collecting plates being located so that the lengthwise direction thereof corresponds to the lateral direction (the direction of the axis x) of each stage of the heat exchanging pipes.

In the evaporative cooling apparatus where serpentine heat exchanging pipes are employed, there is a defect that the loss of cooling efficiency is brought about by insufficient utilization of the latent heat by evaporation of the coolant liquid. More specifically, a part of the coolant liquid does not participate in the evaporative cooling action in each stage of the heat exchanging pipes. The coolant liquid flowing down from the liquid distributor of the evaporative cooling apparatus dews and wets the surface of heat exchanging pipes of the uppermost stage, and dews and wets successively the surfaces of heat exchanging pipes of lower stages. During this period, a part of the coolant liquid coming from the liquid distributor and a part of the coolant liquid which has dewed and wetted the surfaces of heat exchanging pipes of one stage are passed through the clearances between lines of heat exchanging pipes without dewing or wetting the surfaces of heat exchanging pipes of all or some stages. Thus, a considerable portion of the coolant liquid does not participate in the heat exchange. In such gradual dewing and wetting of serpentine heat exchanging pipes arranged in stages by the coolant liquid, in order to accomplish the desired heat transfer by dewing and wetting the surfaces of the heat exchanging pipes by a prescribed necessary amount of the liquid to such an extent that scales (caused by evaporation of the coolant liquid on the heat exchanging pipe surface) are not formed, it is necessary to supply a greater quantity of the coolant liquid than in the case of successive dewing and wetting of ordinary heat exchanging pipes arranged in stages, which results in economical disadvantages. Furthermore, the resistance to passage of air is increased. Thus, the evaporative heat exchange efficiency is greatly reduced.

Moreover, in case fillers made from a synthetic resin are used as in this invention, since the synthetic resin filler is directly supported on the surface of the heat exchanging pipe, if a process fluid running inside the heat exchanging pipe has such a high temperature as exceeding 100°C., the surface temperature of the heat exchanging pipe increases to soften and degrade the synthetic resin filler. For this reason, an unexpensive and lowly heat-resistant resin such as a vinyl chloride resin cannot be used as a material constituting the filler, and an expensive material having a sufficient heat resis-

tance must be used, which results in rise of the manufacturing costs.

However, these defects and demerits brought about by the use of serpentine heat exchanging pipes can be conveniently overcome by provision of the above-mentioned specific semilunar liquid-collecting plate.

In accordance with a still further feature of this invention, there is provided an evaporative cooling apparatus of the above-mentioned structure, wherein a wavy plate-like eliminator such as illustrated in FIGS. 10 and 11 is provided as the eliminator for preventing splash liquids formed in the outer casing from dispersing outside the outer casing. This eliminator includes wavy vane plates 28 disposed at suitable intervals, for instance, 2 - 3 cm, and laid and supported, on supporting members 29. Liquid droplets separated in the air stream impinge violently against the surface of the wavy plate-like vane plate 28, and flow downwardly thereon while forming a liquid film. In the case of an ordinary zigzag eliminator, the so formed liquid film tends to split off liquid droplets again therefrom, and these droplets disperse outside the outer casing. In such case, the resistance to passage of air is increased, resulting in increase of the pressure loss. Therefore, it is necessary to increase the operation power.

In accordance with a still further feature of this invention, there is provided an evaporative cooling apparatus of the above-mentioned structure, wherein the air outlet side end of the net-like filler is extended into the space on the air outlet side as illustrated in FIG. 12 so that splash liquids formed in the outer casing are auxiliarily removed by the net of the filler before the splash liquids reach the eliminator.

In case a net-like filler for mainly accomplishing diffusion of liquid films, such as mounted to the apparatus of this invention, is provided, the amount of splash liquids is extremely reduced. Therefore, if the net-like filler is extended in a manner as described above, it will be even possible to omit provision of the eliminator.

In accordance with a still further feature of this invention, there is provided an evaporative cooling apparatus of the above-mentioned structure, wherein sea water is used as the coolant liquid and a dry heat exchanger is provided at the air outlet to remove fine droplet splashes of sea water leaking out of the eliminator, especially salt components contained therein.

Since the principle of removal of splash liquids by the eliminator resides in utilization of the flow of air passing through the apparatus, it is difficult to remove completely fine droplet splashes of sea water. Further, if it is intended to remove completely splashes of sea water by an action of the eliminator, the pressure loss of air is increased and a great power is necessary for operating the suction blower sufficiently, which results in economical disadvantages.

In case an ordinary eliminator is used, more than 0.02 percent of circulated sea water is allowed to disperse outside the casing by failure to remove it by an action of the eliminator.

Even when the eliminator of this invention is used, it is difficult to attain complete prevention of dispersion of fine droplet splashes of sea water outside the outer casing, and a very small quantity of sea water is let to disperse outside the outer casing. Thus, the so splashed sea water dispersing outside the outer casing together with waste air gives bad influences to environments of not only the factory but also neighbouring private

houses, and there is a fear of causing a polluttional problem.

The above defects can be completely overcome by provision of a dry heat exchanger of this invention such as illustrated in FIGS. 13 and 14. Namely, fine droplet 5 splashes of sea water that cannot be completely removed by the eliminator can be completely eliminated by an action of this dry heat exchanger without substantial increase of the power for the air-feeding fan. An example of the dry heat exchanger to be used in this invention is illustrated in FIG. 13, and as illustrated in partially cut-out enlarged views of FIGS. 14 and 15, it has a structure including a tube 35 and fins 36 bonded to the periphery of the tube 35.

Removal of scales of salt components (composed mainly of NaCl) deposited on the surface of this finned tube is accomplished in the following manner.

At regular intervals of a suitable period, the suction blower is stopped for a short time, and sea water is sprayed on the dry heat exchanger of the finned tube type from the liquid distributor 34 for supplying sea water, whereby scales are dissolved in the so sprayed sea water. Then, the sea water containing scales dissolved therein is collected in the liquid-collecting basin 13 and discharged from an exhaust opening 11.

Other objects and features of this invention will be apparent from the detailed description given hereinbelow.

FIG. 5 illustrates one embodiment of the evaporative cooling apparatus of this invention. This evaporative cooling apparatus 1 is a cooling apparatus of the double flow suction system including an outer casing 5 provided with air inlets 2 and 3 and an air outlet 4. This invention will now be illustrated by reference to an Example using this evaporative cooling apparatus of the double flow suction system for cooling a process fluid.

Of course, this invention is not limited to the apparatus of the double flow suction system, but it may apply to various modifications including conventional single flow system apparatuses. Accordingly, it must be noted that the term "air inlets" used in the instant specification and claims is sometimes used to mean "an air inlet".

The outer casing 5 has a pair of side walls 6 supported on an inner construction frame of a rectangular parallelepiped form, and along this pair of side walls, air inlets 2 and 3 are provided on both sides of the outer casing. At the central portion of a top wall 7 a suction blower 8 is provided as a ventilator to form an air outlet 4.

A suction blower cover 9 composed of a cylindrical protective frame is mounted on the air outlet 4, and the suction blower 8 is disposed inside the cover 9 to suck air from air inlets 2 and 3 into the casing 5.

As is seen from FIG. 5, air sucked from air inlets 2 and 3 impinges rectangularly against heat exchanging pipes 10 and withdrawn from the air outlet 4.

A bottom wall 11 of a square form of the outer casing has side walls 12 of a relatively narrow width extending vertically from each side edge of the bottom wall 11, and these side walls and bottom wall define a liquid-collecting basin along the total length and total width of the casing 5, for instance, an open liquid collector 13.

A liquid distributor such as illustrated in FIGS. 6 and 7, for instance, a cylindrical liquid distributor 14 having

a double-tube structure, is supported by the inner construction frame and disposed between the air inlets 2 and 3 just below the top wall 7 except for a space 15 formed just below the suction blower 8. A coolant liquid fed to the liquid distributor 14 is separated into streams falling simultaneously from all the openings perforated on the lower portion of the outer tube 26 of the liquid distributor. A liquid distributor of a gutter-like configuration may be used as the liquid distributor 14.

A pump 16 is fitted on the surface plate of the side wall 12, and the suction side of the pump is connected to the liquid-collecting basin 13 through a sucking member and the extrusion side is connected to the liquid distributor 14 through a conduit 17. The pump 16 is so arranged as to feed the coolant liquid upwardly.

A float valve inside the liquid-collecting basin 13 is connected to a suitable liquid supply system to maintain the liquid level necessary for actuation of the pump 16.

Heat exchanging pipes 10 through which a process fluid passes as a fluid to be cooled are disposed inside the outer casing 5 between the liquid distributor 14 and the bottom wall 11 of the liquid collector. Each of heat exchanging pipes 10 meanders in the lateral direction (the direction of the axis *x*) and extends in the vertical direction (the direction of the axis *y*) without substantial protrusion outside the outer casing 5. A plurality of such heat exchanging pipes 10' are disposed in parallel to each other in the lateral direction (the direction of the axis *z*) along the air flow, the upper and lower ends of each heat exchanging pipe 10' are connected to an inlet and an outlet for the process fluid to be cooled. In voids formed between two adjoining stages of the heat exchanging pipes by serpentine configuration of the heat exchanging pipes, fillers for mainly accomplishing diffusion of liquid films, such as illustrated in FIGS. 1 to 3 (fillers 18 composed of net-like segments of an inclined wavy configuration are employed in this Example), are disposed. The manner of arrangement of these fillers is such that the lengthwise direction of the central face of each segment of the filler corresponds to the lateral direction (the direction of the axis *z*) which is substantially perpendicular to the serpentine direction (the direction of the axis *x*) of the heat exchanging pipe and the central face in the widthwise direction of the filler segment extends almost vertically without interruption between the lower end of the heat exchanging pipe of one stage and the upper end of the heat exchanging pipe of the next lower stage.

As illustrated in FIGS. 5 and 9, fillers 18 are disposed on semilunar liquid-collecting plates 19, each of which has several legs 20 as shown in FIGS. 8 and 9. These legs support the semilunar liquid-collecting plate 19 suspended between two adjoining stages of the heat exchanging pipes. In general, a heat-resistant synthetic resin is used as a material constituting the semilunar liquid-collecting plate and legs thereof, but a metal material may be used as a material constituting the legs. At the air outlet a wavy eliminator 21, a part of which is illustrated in FIGS. 10 and 11, is provided to prevent splash liquids formed in the outer casing from dispersing outside the outer casing. A conventional zigzag eliminator may be employed as the eliminator 21. In this invention, in case fillers of net-like segments are employed, according to need, the air outlet side end of

the filler is extended into the space on the air outlet side (the extended portion being designated by referential numeral 30) so that splash liquids formed in the outer casing 5 are auxiliarily removed by the net of the filler before the splash liquids reach the eliminator 21.

In case sea water is used as the coolant liquid, in this invention a dry heat exchanger 31 such as illustrated in FIGS. 13, 14 and 15 is provided according to need so as to remove fine droplet splashes of sea water leaking out of the eliminator, especially salt components contained therein.

The operation of the evaporative cooling apparatus of this invention will now be detailed.

Air is fed into the outer casing 5 from air inlets 2 and 3 by actuating the suction blower 8 and allowed to pass laterally upwardly through the cooling units of heat exchanging pipes 10 and fillers 18. Then, air is introduced into the vacant space 15 in the outer casing and finally discharged from the air outlet 4.

Air crossing through the filler 18 passes mainly through a void formed by two adjoining segments, as illustrated in FIGS. 1-3.

The pump 16 is driven to feed the coolant liquid upwardly into the liquid distributor 14 from the liquid collecting basin 13 surrounded by the bottom wall 11 and side walls 12 through the conduit 17.

As is illustrated in FIG. 6, the coolant liquid is allowed to fall down from the liquid distributor 14 through a series of distribution openings 26, and this falling liquid flows downwardly onto liquid-collecting plates 19 positioned above heat exchanging pipes 10 of the uppermost stage while taking a form of a film-like jet stream and is collected on the uppermost surface of the each of individual heat exchanging pipes 10' to wet sufficiently pipes 10' and accomplish the heat transfer effectively. Then, the coolant liquid falls on the filler 18 and the evaporative cooling thereof is accomplished by air passing horizontally through the filler 18. The so cooled coolant liquid is then collected on the liquid-collecting plates 19 positioned above the heat exchanging pipes 10' of the next lower stage, and wets the heat exchanging pipes of this stage entirely. A process fluid to be cooled is introduced through a fluid inlet 22 to the upper end of each of the heat exchanging pipes. Thus, when the coolant liquid wets the heat exchanging pipes 10 at the upper stage, the temperature of the coolant liquid is elevated by the heat exchange and the temperature of the process fluid passing through the heat exchanging pipes is lowered.

The elevation and lowering of the temperature of the coolant liquid are repeated alternately while it travels through the stages of the heat exchanging pipes, liquid collecting plates and fillers in the above manner, whereby the process fluid is cooled successively. The cooling of the process fluid is continued throughout the period during which the process fluid falls down along the entire vertical height of the structure of the heat exchanging pipes and is finally collected in the liquid-collecting basin 13. Thus, the cooling is completed when the process fluid introduced from the fluid inlet 22 is withdrawn from the fluid outlet 23.

Splash liquids formed in the outer casing are removed by an eliminator such as illustrated in FIGS. 10 and 11. Such splash is partially removed by extending the air outlet side end of the net-like filler into a space on the air outlet side as illustrated in FIG. 12.

In case sea water is used as the coolant liquid, fine droplet splashes of sea water leaking out of the eliminator to some extent are evaporated momentarily on the surface of the finned outer tube of the dry heat exchanger 31, to thereby deposit salt components contained in sea water on the surface of the finned outer surface, while the vapor formed by the evaporation is withdrawn outside the outer casing. At regular intervals of a suitable period, the suction blower is stopped for a short time, and sea water is sprayed on the dry heat exchanger 31 of the finned tube type from the liquid distributor for supplying sea water, whereby scales (composed mainly of NaCl) are dissolved in the so sprayed sea water. Then, the sea water containing scales dissolved therein is collected in the liquid-collecting basin 13 and discharged from the exhaust opening. As the heat source for the dry heat exchanger, the high temperature of the fluid to be cooled is effectively employed.

The effects attained by fillers according to this invention will now be illustrated by reference to FIGS. 16 and 17. FIG. 16 illustrates the difference of the pressure loss per meter of the filler between the case where the conventional filler disclosed in Japanese Patent Publication No. 1066/67 (U.S. Pat. No. 3,141,308) is employed and the case where the filler of this invention such as shown in FIGS. 1 to 3 is employed. FIG. 17 illustrates the difference of the overall heat transfer volume coefficient at each flow rate of air between the case where the above-mentioned conventional filler is employed and the case where the filler of this invention is used. In FIGS. 16 and 17, curves (1) and (1') are those obtained when cypress slat fillers of the above prior art are employed, curves (2) and (2') are those obtained when wavy plate-like fillers shown in FIG. 1 are used, curves (3) and (3') are those obtained when fillers of wavy net-like segments shown in FIG. 2 are employed, and curves (4) and (4') are those obtained when fillers of wavy net-like segments shown in FIG. 3 are employed. In each of FIGS. 16 and 17, there are shown results obtained when the amount of falling water per unit area of the filler per the unit time is adjusted to 20 tons per hour.

From the results shown in FIGS. 16 and 17, it will readily be understood that in effecting the heat transfer by evaporation of a coolant liquid by passing air through a vessel of a certain dimension under certain air pressure, to increase the liquid surface area by flowing the coolant liquid in the form of a film flow is more advantageous from the economical viewpoint than to increase the surface area by forming liquid drops as much as possible in the vessel, because the former procedure can control effectively the pressure loss and maintain the contact between the coolant liquid and air for a much longer period.

What we claim is:

1. An evaporative cooling apparatus which comprises an outer casing provided with an air inlet and an air outlet; a cooling unit for continuously and indirectly cooling a fluid to be cooled, said cooling unit including a plurality of heat exchanging pipes of a serpentine configuration meandering in the lateral direction (the direction of the axis *x*) which extend in the vertical direction (the direction of the axis *y*) without substantial protrusion outside the outer casing and are disposed in parallel to each other in the lateral direction (the direction of the axis *z*) along the air flow, the upper and

lower ends of each of said heat exchanging pipes being connected to an inlet and an outlet for a fluid to be cooled, respectively; fillers for mainly accomplishing diffusion of liquid films which are disposed in voids formed between two adjoining stages of the heat exchanging pipes so that the lengthwise direction of the central face of each segment of the filler corresponds to the lateral direction (the direction of the axis z) rectangular to the serpentine direction (the direction of the axis x) of the heat exchanging pipe of the cooling unit and the central face in the widthwise direction of the filler segment extends almost vertically without interruption between the lower end of the heat exchanging pipe of one stage and the upper end of the heat exchanging pipe of the next lower stage; a fan for passing air through said cooling unit; a cylindrical double-tube liquid distributor for sprinkling a coolant liquid to said cooling unit, said distributor comprising an outer tube closed at both ends and a liquid feed tube inserted in said outer tube, liquid outlets being perforated at suitable intervals on the lower portion of said outer tube and liquid overflowing openings being perforated on the liquid feed tube; a basin for receiving the coolant liquid which has been sprinkled from said liquid distributor and flown downwardly through the cooling unit; and an eliminator provided to prevent splash liquids formed in the outer casing from dispersing outside the outer casing.

2. An evaporative cooling apparatus as set forth in claim 1 wherein the filler segments are wavy plate-like segments.

3. An evaporative cooling apparatus as set forth in claim 1 wherein the filler segments are net-like segments.

4. An evaporative cooling apparatus as set forth in claim 3 wherein the net-like filler segment is one having a wavy configuration.

5. An evaporative cooling apparatus as set forth in claim 4 wherein net-like filler segments of a wavy configuration are disposed in parallel to each other so that crests and troughs of every two adjoining segments confront each other and a prescribed distance is formed between the adjoining segments.

6. An evaporative cooling apparatus as set forth in claim 1 wherein semilunar liquid-collecting plates are provided between two adjoining stages of the heat exchanging pipes to collect the coolant liquid flowing downwardly along the fillers disposed between said two adjoining stages of the heat exchanging pipes on the heat exchanging pipes of the lower stage, each of said semilunar liquid-collecting plates being located so that the lengthwise direction thereof corresponds to the lateral direction (the direction of the axis x) of each stage of the heat exchanging pipes.

7. An evaporative cooling apparatus which comprises an outer casing provided with an air inlet and an air outlet; a cooling unit for continuously and indirectly cooling a fluid to be cooled, said cooling unit including a plurality of heat extending pipes of a serpentine configuration meandering in the lateral direction (the direction of the axis x) which extend in the vertical direction (the direction of the axis y) without substantial protrusion outside the outer casing and are disposed in parallel to each other in the lateral direction (the direction of the axis z) along the air flow, the upper and lower ends of each of said heat exchanging pipes being connected to an inlet and an outlet for a fluid to be

cooled, respectively; fillers for mainly accomplishing diffusion of liquid films which are disposed in voids formed between two adjoining stages of the heat exchanging pipes so that the lengthwise direction of the central face of each segment of the filler corresponds to the lateral direction (the direction of the axis z) rectangular to the serpentine direction (the direction of the axis x) of the heat exchanging pipe of the cooling unit and the central face in the widthwise direction of the filler segment extends almost vertically without interruption between the lower end of the heat exchanging pipe of one stage and the upper end of the heat exchanging pipe of the next lower stage; a fan for passing air through said cooling unit; a liquid distributor for sprinkling a coolant liquid to said cooling unit; semilunar liquid-collecting plates suspended between two adjoining stages of the heat exchanging pipes to collect the coolant liquid flowing downwardly along the fillers on the heat exchanging pipes, each of said semilunar liquid-collecting plates being located so that the lengthwise direction thereof corresponds to the lateral direction (the direction of the axis x) of each stage of the heat exchanging pipes; a basin for receiving the coolant liquid which has been sprinkled from said liquid distributor and flown downwardly through the cooling unit; and an eliminator provided to prevent splash liquids formed in the outer casing from dispersing outside the outer casing.

8. An evaporative cooling apparatus, comprising: housing means;

a cooling unit disposed within said housing means for continuously and indirectly cooling a fluid to be cooled;

said cooling unit including a plurality of heat exchanger pipes adapted to have said fluid flow there-through, each of said heat exchanging pipes being of a serpentine configuration defining a substantially vertical plane and including a plurality of approximately horizontally extending pipe sections which are vertically spaced from one another and a plurality of intermediate pipe sections extending vertically between and interconnecting the horizontal pipe sections, said plurality of heat exchanging pipes being horizontally spaced from one another in substantially parallel relationship, the upper and lower ends of said pipes being connected to an inlet and an outlet for said fluid to be cooled;

distributor means associated with said cooling unit and disposed thereabove for sprinkling a cooling liquid onto said unit;

said cooling unit further including filler means disposed within the void formed by said heat exchanger pipes for receiving thereon said cooling liquid and for diffusing the liquid films, said filler means including a plurality of vertically spaced filler assemblies each extending in a direction substantially perpendicular to the vertical planes defined by the serpentine configuration of said heat exchanging pipes and disposed so as to substantially occupy the space defined between a pair of vertically adjacent horizontal pipe sections;

each said filler assembly including a plurality of sheetlike segments disposed so that the lengthwise direction of each extends substantially perpendicular to the substantially vertical planes defined by the serpentine configuration of said heat exchange-

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ing pipes, each of said sheetlike segments having a vertically extending width which is uninterrupted and is substantially equal to the vertical spacing between the vertically adjacent pair of horizontal pipe sections, said sheetlike segments defining therebetween substantially horizontally extending passages which extend in a direction substantially perpendicular to the substantially vertical planes defined by the serpentine configuration of said heat exchanging pipes, said passages permitting flow of air therethrough;

said housing means including air inlet means associated therewith for permitting air to be supplied to one end of said horizontally extending passages, said housing means also including air outlet means associated therewith for permitting air to be withdrawn from the other end of said horizontally extending passages; and

collecting means disposed below said cooling unit for receiving and collecting therein the cooling liquid which flows downwardly through said cooling unit.

9. A cooling apparatus according to claim 8, further including suction blower means associated with said outlet means for drawing air through the passages defined in said cooling unit.

10. A cooling apparatus according to claim 8, further including eliminator means associated with said outlet means for preventing splash liquids from being dispersed outside said housing means, said eliminator means including wavy vanelike plates supported at spaced intervals and disposed adjacent said other end of said passages.

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11. A cooling apparatus according to claim 8, further including a second cooling unit disposed within said housing means and horizontally spaced from said first-mentioned cooling unit, said second cooling unit being substantially identical to said first-mentioned cooling unit, said cooling units being spaced a substantial distance apart to define therebetween a flow channel comprising a portion of said air outlet means, said flow channel extending substantially vertically, and fan means associated with the upper end of said channel for drawing air through the passages of the respective cooling units into said channel and for discharging said air into the surrounding atmosphere.

12. A cooling apparatus according to claim 8, wherein said distributor means includes an outer tube which is closed at both ends and is provided with a plurality of liquid outlets perforated at suitable intervals on the lower portion thereof, and an inner liquid feed tube disposed within said outer tube and being provided with liquid overflow openings formed in the upper portion thereof for permitting flow of liquid from said inner feed tube into said outer tube.

13. A cooling apparatus according to claim 8, further including elongated liquid collecting plates disposed directly above each of said filler assemblies, said plates being disposed in substantially parallel relationship and being elongated in a horizontal direction which is substantially parallel to said horizontal pipe sections, each of said liquid collecting plates being of a downwardly opening arcuate configuration when viewed in cross section.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3 820 353

Dated June 28, 1974

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Inventor(s) Senji Takenaka, Nobuo Yamada and Motoyoshi Hashitani

It is certified that error appears in the above-identified patent
and that said Letters Patent are hereby corrected as shown below:

Col. 13, line 30; change "Claim 1" to ---Claim 8---.

Col. 13, line 33; change "Claim 1" to ---Claim 8---.

Signed and sealed this 12th day of November 1974.

(SEAL)

Attest:

McCOY M. GIBSON JR.
Attesting Officer

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Commissioner of Patents