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(54) **A cell type air humidification system for industrial purpose**

Eine zellenartige Luftbefeuchtungsanlage für industrielle Anwendung

Un système d'humidification du type cellulaire destiné à l'usage industriel

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- **PATENT ABSTRACTS OF JAPAN vol. 9, no. 111 (M-379) (1834) 15 May 1985 & JP-A-59 231 339 (TORINITEI) 26 December 1984**

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Description

Background of the invention :

[0001] This invention relates to a cell type air humidification system for industrial purpose, and,in particular, it pertains to air washer with fabric cell for enhanced surface evaporative saturation. This invention at some places in this document may be referred to as ATIRA invention since it was carried out at the Ahmedabad Textile Industry's Research Association Ahmedabad, India (ATIRA).

PRIOR ART

COMPARATIVE STUDY

[0002]

1. Capillary Air Washer of Carter Industrial Products, LONDON, UK.
Known Technology
Cell Size : 50x50cm (10cm depth) [20" x 20" (4" depth)].
Random packing of fibrous material. Very minimal energy saving if at all.
Novel features of ATIRA invention - Nominal size 122x61 cm (91.5 cm depth) [48"x24" (36" depth)]. Different configuration of cell and material. Uniform spacing of vertically disposed fabric layers of non-hygroscopic, non-cellulosic and non-bio-degradable material, and/or being duly processed, to achieve bulkiness, good water holding capacity, absorbency, spreading and wetting characteristics. Acts mainly as evaporator and also as air straightener cum partial water stripper. Less resistance to air flow and therefore reduced fan power by about 35%. About 90% reduction in pump power because of reduced flow and low water pressure compared with existing spray type air washer.

2. Capillary Air washer of Air Refrigeration Corporation New York, U.S.A.
Known Technology
Cell Size : 50x50 cm and (20 cm depth) [20"x20" and (8" depth)]
Glass filament as packing material, Random Packing.
High air resistance of 2.6 kPa (27 mm of WC) at 165 m/min. (550 FPM) air velocity.
Not possible to use above 120 m/min (400 ft/min.) air velocity.
Novel features of ATIRA invention - Nominal size 122x61cm (91.5 depth [48" x 24" (36" depth)]. Different configuration of cell and material. Uniform spacing of vertically disposed fabric layers of non-hygroscopic, non-cellulosic and non-bio-degradable material, and/or being duly processed, to achieve bulkiness, good water holding capacity, absorbency, spreading and wetting characteristics. Act mainly as evaporator and also as air straightener cum partially water stripper. Low resistance to air flow of 0.78 to 0.98 kPa (8 to 10 mm of WC) at 165 m/min. (550 FPM) air velocity. Used upto 180 m/min. (600 ft/min)air velocity without deterioration of performance. About 90% reduction in pump power because of reduced flow and low water pressure compared with that of existing spray type air washer.

3. Aerofil Evaporative cooler of Buffalo Forge Co, New York, U.S.A.
Known Technology
'AEROFIL' capillary air media made of cellulose or fibre glass. Flute or corrugated air running alternatively at 15 and 45 angle.
No saving of fan power.
Recirculated water rate is less than sprayed coil units reducing pump power.
Novel features of ATIRA invention - Uniform spacing of vertically disposed fabric layers of non-hygroscopic, non-cellulosic and non-bio-degradable material, and/or being duly processed, to achieve bulkiness, good water holding capacity, absorbency, spreading and wetting characteristics. Fabric layers are parallel to air flow. Less resistance to air flow and so reduced fan power by about 35%. About 90% reduction in pumping power because of reduced flow and low water pressure compared with existing spray type air washer.

4. High Efficiency mass transfer in multi-phase processes of Glitsch Inc. U.S.A.
Known Technology
Spiral wound metalpack having met pace with double concentric structure with knitted tube made of stainless steel wire used mainly in distillation tower.
Low pressure drop (range of value not specified).
Not used in evaporative cooling system.
Horizontal mounting. No mention of vertical mounting i.e. gas flow is in vertical direction only.

Novel features of ATIRA invention - Uniform spacing of vertically disposed fabric layers of non-hygroscopic, non-cellulosic and non-bio-degradable material, and/or being duly processed, to achieve bulkiness, good water holding capacity, absorbency, spreading and wetting characteristics. Parallel fabric layers. Less pressure drop of 0.78 to 0.98 kPa (8 to 10 mm of water). Specially used for evaporative cooling system. Air flow is in horizontal direction. Fan power saved by about 35%.

5. Plastic Packing Evaporator of Visco Serck Stafford Road, Croydon, U.K.

Known Technology

For Cooling towers. No mention of cooling of air.

Plastic packing.

Drift eliminators with low air resistance.

No appreciable energy conservation.

Novel features of ATIRA invention - For air washer. Uniform spacing of vertically disposed fabric layers of non-hygroscopic, non-cellulosic and non-bio-degradable material, and/or being duly processed, to achieve bulkiness, good water holding capacity, absorbency, spreading and wetting characteristics. Water stripping device with low air resistance. Less resistance to air flow and so fan power reduced by about 35%. About 90% reductions in pump power because of reduced flow and low water pressure compared with existing spray type air washer.

6. Evaporative cooler with FRP material of Mihir Engineering, Bombay, INDIA.

Applications - comfort cooling in Buildings, Offices, Restaurants.

Low cooling efficiency. No industrial applications.

Capacity 1415 l/sec (3,000 CFM) to 9440 l/sec (20,000 CFM).

PVC as evaporative pad.

Low saturation efficiency as evaluated by ATIRA, saturation efficiency was found to be about 65-70%.

Sufficient cooling but not suitable for industrial applications.

Low air/water pressure drop.

Novel features of ATIRA invention - Application Industrial air washer. Large capacity 2360 l/sec (5,000 CFM) to 707,900 l/sec (1,500,000 CFM). Uniform spacing of vertically disposed fabric layers of non-hygroscopic, non-cellulosic and non-bio-degradable material, and/or being duly processed, to achieve bulkiness, good water holding capacity, absorbency, spreading and wetting characteristics. High saturation efficiency. Less resistance to air flow and so fan power reduced by about 35%. About 90% reduction in pump power because of reduced flow and low water existing spray type air washer.

7. Capillary Air Washer of Carter Industrial Products Ltd. U.K.

Known Technology

For cooling tower.

Knitted polypropylene filament as cell material.

No appreciable energy conservation.

Novel features of ATIRA invention - For air washers. Uniform spacing of vertically disposed fabric layers of non-hygroscopic, non-cellulosic and non-bio-degradable material, and/or being duly processed, to achieve bulkiness, good water holding capacity, absorbency, spreading and wetting characteristics. Less resistance to air flow and so fan power reduced by about 35%. About 90% reduction in pump power because of reduced flow and low water pressure compared with existing spray type air washer.

8. Cell Type Air Washer (Wood-Wool Cell) ATIRA.

Known Technology

Size 50x50 cm (20 cm of depth) [20" x 20" (8" of depth)] of cell.

Random packing of wood wool and coir as cell material.

90% saving in pumping power.

Novel features of ATIRA invention - Size 10x5cm (7.5 cm depth) [4' x 2' (3' depth)] of cell. Uniform spacing of vertically disposed fabric layers of non-hygroscopic, non-cellulosic and non-bio-degradable material, and/or being duly processed, to achieve bulkiness, good water holding capacity, absorbency, spreading and wetting characteristics. Less resistance to air flow and so fan power reduced by about 35%. About 90% reduction in pump power and low water pressure compared with existing spray type air washer.

[0003] The following patents were also found in similar area of technology but did not teach any of the novel features of this invention.

UNITED KINGDOM 2255034 A	Abrasive recovery system for blasting device - has main and secondary separator with comprising air washing systems and both fed with air from common ducting
BRAZIL 8902712	Air washer and acid vapour neutraliser has pre-washing spray duct, successive

	beds of polypropylene spheres with countercurrent flow of neutralising liquid.
UNITED STATES 4810268	Air washer with vanes to swirl the flow of air - has nozzles mounted adjacent to housing circumference for directing a spray of water in a swirling motion across the airflow.
GERMANY 3546232	Air washing installation has air flow straightener formed by two parallel rows of vertically mounted tubes or bars.
EUROPEAN PATENT 160437	Air conditioning system for large buildings and processing areas includes air washing and moisture removal stages in production of clean air at controlled temperature and humidity.
GERMANY 3017166	Air washing unit for staple ventilation has air flow guided by baffles under sprays and above two-section sump.

Brief summary of the invention :

[0004] The humidification system according to this invention, designed for industrial use, operates on the principle of evaporative cooling or adiabatic saturation, wherein Dry Bulb temperature (DB) of the air decreases and most ideally it becomes equal to the Wet Bulb temperature (WB) of air. The temperature of the water in the system also becomes equal to the Wet Bulb temperature. The relative humidity (RH) of the air delivered by the humidification plant should ideally be 100%. However, for design calculation, it is considered to be satisfactory if the RH is 92-94% indicated by 0.5°C (2°F) difference between DB and WB temperature of the air usually called as depression. The cooled and high humid air is distributed in the departments, where desired RH for smooth working of the manufacturing process is to be maintained. The air, which is supplied, absorbs the departmental heat that consists of the heat generated by the production machinery, lighting load, workers and that transmitted through walls, windows and roofs. So the RH in the department is lower than RH of the supply air, because of the absorption of departmental heat. The total heat load and the capacity of the humidification system in terms of mass flow of air is so matched that the desired RH for smooth working of the process is maintained in the department.

[0005] A considerable amount of heat and mass transfer between air and water occurs in many equipments like cooling towers, evaporative air coolers and condensors, air washers and the like. Essentially all these are evaporative type heat exchangers, each of different designs, characteristics and application. Considering the air washers, the conditioned air created by them is used at many industrial applications like food, pharmaceutical, printing, textile manufacturing and so on. Conventionally, spray type air washer is used at many places where pressurised water is sprayed in a chamber across which air is passed. The evaporative cooling is achieved by spraying huge quantity of pressurised water that is atomised through suitable systems consisting of spray nozzles/water atomisers, water filters, eliminators, all assembled as one unit called air washer. For heat and mass transfer between air and water, large surface area of water is created by breaking the water into minute particles. Only a fraction of the sprayed water is evaporated and absorbed by the moving air, the rest partly falling back and partly being suspended in the air. The latter part which is suspended in the air, is to be removed before the air is to be delivered to the duct in the department. The ratio of the amount of water sprayed to that evaporated in the air is usually 100 to 200. Thus a large amount of water is necessary to be pumped and sprayed to create the required surface area for heat and mass transfer. However, in the existing arrangements the surface area once created through atomisation gets destroyed when the free water particles fall into the sump. Also efficient eliminators are required to remove the large number of water particles from the air. Since the surface area gets destroyed when sprayed water falls down in the tank below the spray chamber, there is a need to create it repeatedly and continuously, necessitating large quantity of high pressure water to be pumped continuously.

[0006] Further, the eliminators which are provided to remove free water from the air, offer high resistance to air flow. This leads to consumption of considerable amount of energy. The existing air washer is called spray type air washer (hereinafter referred to as "STAW").

[0007] Another type of air washer, developed by the Applicants herein, is of the cell type, in which extended interfacial surface area is provided by wetting a suitable material packed in the form of cells, the material of packing having typically been wood -wool supported by coir. This invention is described in our Indian Patent Specification No. 169242. The performance of the cell type air washer (hereinafter referred to as CTAW), gives equivalent result to that of the spray type air washer (STAW), but without requiring pressurised water and with much less amount of water flow and hence using much less pumping power.

[0008] FR-A-502 309 discloses a cell type air humidification device as defined in the precharacterizing portion of independent claim 1, wherein the air is caused to move through metal wool layers. DE-A-40 06 319 discloses a laminar humidifier in which the air flow moves over wetted coated metal or plastic material layers. GB-A-1 363 523 discloses a device and method for bringing into contact a gaseous fluid and a liquid to transfer matter and/or heat between them. The liquid is caused to flow along multi-stranded yarns which may be textured and twisted and consist of materials such as polyamide, polyester, polypropylene and glass fibers.

Object of the invention:

[0009] The object of the present invention is to provide efficient and effective cell type air humidification system for industrial purpose with a view to create extended surface area to enhance heat and mass transfer between air and water.

[0010] In achieving the above object, instead of atomising, the required surface area of water for heat and mass transfer is created by taking the help of a water supporting matrix for which fabric has been found to be most ideal. The mechanical power to break water to create surface for heat and mass transfer, as in conventional STAW, is avoided. Only a small quantity of water is sprayed on the face of the cells which are filled with suitable geometry of fabric. The fabric is so designed and selected as to create surface area of water by spreading it over the fabric, for which the fabric is imparted absorbent or hygroscopic qualities, on the one hand, and good water holding capacity, on the other hand. Further, the fabric must be such that even when wet, it must have sufficient strength, not to sag or yield or tear, when subjected to the weight of the absorbed water. From the point of view of such strength requirement, the material of the yarn suitable for application in the present invention are nylon, polyester, polypropylene filaments/yarns/fibers, glass fibers. But, all these materials are inherently non-hygroscopic and non-absorbent. So, in order to obtain hygroscopic properties even in such materials, two approaches are adopted with respect to the yarn structure, which form important part of the specifications of the fabric of the cell type air washer of the present invention, which are, inter alia, (1) selection of multi-fibre or multi-filament, instead of mono-filament type of yarn configuration, and (ii) special processing treatment, such as texturizing of the yarn which through surface roughening effect at a microscopic level, imparts qualities of absorbency and water holding capacity to the fabric. Even if the fabric is made of non-absorbent materials, the physical arrangement of the fibres and the yarns in the fabric makes the fabric absorbent to water and helps to spread the water as soon as it comes in contact with the fabric. This is achieved, for example, by the texturising process of the yarn made of several straight filaments of non-absorbent materials such as polyester before the cloth is woven. The surface area of the cloth is so provided as to be sufficient to provide enough area of water to achieve the final saturation shown by 0.5°C (2°F) depression of the delivery air, as discussed hereinbefore. Thus, large quantity of water is not required to be continuously atomised/sprayed in the system according to this invention. The ratio of the amount of water sprayed and that evaporated drops to about 10 from about 100-200 in STAW. Also the water is not to be atomised as in STAW. This means that the water need not be under high pressure as in STAW and hence the requirement of power for spray water in the improved device according to the invention, is reduced, which come to be upto by about 90%, less as compared with that in STAW for the same capacity of the plant and performance. The capacity of the plant is measured in terms of volume/mass flow rate of air and performance in terms of saturation of delivered air.

[0011] Since the amount of water sprayed is reduced by about 90%, it is not necessary to provide powerful eliminators as those provided in STAW. This reduces the total resistance of the air flow by CTAW. Experimentally it is found that the resistance by CTAW drops to about 3.3 to 4.7 kPa (7 to 10 mm of water) from about 9.4 - 15.9 kPa (20-25 mm of water) in STAW. This has reduced power consumption by the supply air fan (SAF) also, by about 30-35%.

[0012] Thus CTAW according to the invention, reduces electrical energy need by about 90% on water pump and by about 30-35% on SAF's.

Detailed Description:

[0013] Accordingly, the present invention provides a cell type air humidification system for industrial purpose, comprising a humidification chamber, means for providing continuous supply of water onto the said humidification chamber, and means for blowing, sucking air through the said humidification chamber, said humidification chamber being constituted by one or more cells, the said cell or each of the said cells having vertically disposed and uniformly spaced layers of material, housed in a rectangular frame, whereby the required extensive wetted area, with high degree of openness to air flow is caused to be provided for effective heat and mass transfer between the moving air and the water, said material being of the non-hygroscopic, non-cellulosic and non-bio-degradable type, characterized by the layers of material being fabric layers and air being caused to move over the wet surface along the width of the fabric layers, which substantially conforms to the depth of the said cell or each of the said cells, said fabric having such properties as good water holding capacity, absorbency, spreading and wetting characteristics, all of which being essential to enable highly effective saturation of large volume air stream at high velocity, typically, the said fabric being made of Nylon, polyester, polypropylene filaments/yarns/fibres, glass fibres and the like, duly processed by texturising along with twisting configuration for providing appropriate geometry of the fabric to achieve the said characteristics, and further the said fabric being of selected multi-fibre or multi-filament yarn, instead of mono-filament type of yarn configuration, to impart the said characteristics to the fabric.

[0014] The main design criterion is to provide enough evaporative area (defined hereinafter) by wetted fabric to achieve 92-94% RH in given space with high degree of openness (defined hereinafter) of 97%-98% of the overall space of the cell, that will keep the power consumption by the fans also, low. The air delivered by the supply air fans has lot

of turbulence which are broken by straighteners as will be described hereinafter. Any air borne water which is likely to escape from the cells are removed by water stripping device, to be described hereinafter. The recirculating water is continuously filtered by suitable filters.

[0015] The cell may be made of rectangular frame fabricated from mild steel (MS) powder coated or stainless steel (SS) or fibre glass reinforced plastic (FRP) in which vertical layers of fabric are supported tightly by the SS rods attached to the rectangular frame. The vertical configuration provides good and quick water spreading. The extra precautions are required such as better coating of MS, required to prevent corrosion, since it remains continuously in water. The supporting rods for the fabric are made of SS. There is tightening arrangement for the fabric in the cell.

[0016] The fabric is desirably in grey form and desized.

[0017] Although the fabric is made non-cellulosic fibres, it acquires good absorbency, spreading and wetting characteristics and good water retaining capacity and has enough strength against the air force. Preferably, the fabric width is 900mm (36") and the selvage is made of strong filament usually nylon material. The width of both the selvages is around 25mm. This is to prevent the flapping of the fabric in the front where the turbulent air is entering the cell and to provide high tearing strength of the fabric particularly on the selvages. The frame is provided with provision for fixing of the rods at the end of the fabric so that it can be tightened by the mill workers without referring to the manufacturers in case the fabric slackens in the mills. The fabric of the cells acts as an evaporator.

[0018] In a preferred embodiment, the means for providing continuous supply of water comprises a water spraying arrangement, disposed at one side of the or each of the said cell(s) of the humidification chamber, said water spraying arrangement being constituted by a plurality of nozzles for spraying water onto the fabric layers concurrently with the air flow, and being connected to a water supply line, a water collecting tank disposed at the bottom of the humidification chamber, and a water pump for supplying water, under required pressure, to the said water supply line, and, if desired, said water pump having connection with the said water collecting tank for recirculation of the collected water and spraying thereof on to the cells mounted in the humidification chamber.

[0019] The water is sprayed by special nozzles, meant for spraying and not atomising, made of gun metal and stainless steel of orifice e.g. having 2 to 5 mm diameters. The water is pumped by a suitable pump to create pressure e.g. of 73.5 to 147 kPa (0.75 to 1.5 kg/cm). That will be just sufficient to avoid atomization of water. The return water from the air washer collecting tank is, preferably, first filtered by two stage filters provided in the water collecting tank at the bottom of the cells. The water passes through a coarse water filter made of e.g. 20Gx20M water filter, preferably made of stainless steel. The water is then passed through a second filter, made of fine filter e.g. of 40Gx40M. Further the water is filtered by a large size pot strainer after the pump. This pot strainer is made of very fine wire mesh having of e.g. 40G x 40M to 60Gx60m. The size of the water filter is several times larger than the size of the pump in terms of diameter of the delivery pipe. This is to provide large area of the filter in the small piping system. The water is continuously sprayed over the fabric cells avoiding frequent drying and wetting phenomenon, even when it is not necessary, such as when there is rain and evaporation of water ceases and consequently, the spray of water is not required continuous spray of water that does not evaporate during rainy season, helps to remove the dust, dirt etc from the air flowers through the air washer chamber, as otherwise the foreign matters of the air, removed by wetting on the water film and the wetted fabric, will go into the manufacturing department, and cause problems of cleanliness.

[0020] Preferably, the humidification chamber is provided with air straightener(s) constituted by vertically disposed louvres, said louvres being disposed and/or adapted to be moved such as to cause entry of air into the humidification chamber in straight manner without any turbulence.

[0021] In cell type air washer fan is installed in front of the air washer, whereby lot of turbulence of air creates problems of variation of velocity from one cell to another. Sometimes it creates very high velocity of air to some of the cells that damages the fabric and also creates problems of carry over of water particles. To avoid these problems, air straighteners are installed before the spray nozzles. The straighteners are made of either PVC or Polycarbonate or Powder Coated MS or stainless steel sheets/strips.

[0022] Also preferably, the humidification chamber is provided with water stripping device constituted by one or more layers(s) of non-corrosive material, such as herein described, said layer(s) being disposed downstream the, or each of the said cell(s) of the humidification chamber, whereby air borne water is caused to be removed. The said layer(s) constituting the water stripping device is(are) preferably of "V" shape for causing sharp turn of air-flow passing through the same, whereby free water suspended in the air is caused to be removed from the air.

[0023] Since the quantity of water sprayed in the air is very small compared to that in the case of STAW (about 1/10th that of STAW) and it is also not atomised, a few number of the Vee shape blades are required to be installed after the cells. Thus, the space between the Vee Shape blades is about 50 to 75 mm as compared to that about 25mm between the eliminator blades in the case of STAW.

[0024] In a particular embodiment the fabric layer(s) of the or each of the said cell(s) is(are) held in the rectangular frame by means of rods of non-corrosive material, such as herein described, laterally provided at the top and bottom ends of the frame, said rods being adapted to be used for support of the fabric, wrapped over the same in successive manner, and used for tightening/loosening the fabric, as and when desired, according to requirement.

[0025] The system according to the invention works on evaporation, leaving all the dissolved solids and hardness of water, on the fabrics and the run-down water in to the sump at the bottom of the humidification chamber. Also, fabric is loaded with scale formation which is to hamper the life of the fabric. It is, therefore, necessary to use soft water that will not create hard scale. It is, therefore, desirable to use rain water if available. Continuous overflow of the water from the sump of the humidification chamber may be provided to maintain the level of total dissolved solids in the sump. To minimise the deposition on fabric, water should be sprayed over the fabric all the time even when not required such as during rainy season, as explained hereinabove, so that the fabric remains covered with a film of water on which any deposits of the salt may take place and get washed away with flow water of the fabric without getting deposited on the fabric.

[0026] Preferably, the water supply line of the spraying arrangement is provided with filter(s)/pot-strainer for supply of filtered water onto the humidification chamber. Water cleaning/descaling arrangement may be provided for supply of clean water, through the water spraying arrangement, onto the humidification chamber. The water supply line of the spraying arrangement is preferably provided with by-pass arrangement for desired control of water flow. Stand-by spraying arrangement is preferably provided in combination with the said water spraying arrangement for use thereof in continuous supply of water onto the humidification chamber, in the event of failure of the said water spraying arrangement or for its stoppage during maintenance.

[0027] The frequency of cleaning of the air washer system according to this invention, is and can be decided according to the type of industry. For example, in the textile industry spinning man-made fibres using the system will have very less frequency of cleaning as compared to the same industry where coarse count cotton spinning is involved, because, the former generates little fluff in the department whereas the latter generates large quantity of fluff and dust. Similarly the industry using rain water, which is almost distilled water, will practically need no water treatment, as compared to those industries using bore water having high TDS and hardness resulting in heavy scale formation. The descaling procedure should be by HCL of 5% or less concentration in water sprayed over the cells in situ without dismantling the air washer. The cleaning can also be done by removing the cells and dipping into a tank filled with dilute acid. It may also be possible to clean the cells to remove the scale formation by brushing with mild acid with the help of suitable brushing system. Thorough washing should be made with fresh water after which a caustic wash is needed. An about 2% concentrate of NaOH or KOH is necessary after the acid wash to neutralize the traces of the acid to prevent corrosion. However to eliminate the problems of cleaning and possible corrosion of air washer tank and supporting structure it is recommended to use demineralized water.

[0028] As preferred embodiment, the width of the fabric layers in the cell is minimum 3 ft (or 90 cm) which is the depth of the cell also. The spacing between the fabric layers may be determined, depending on the desired evaporative area, and desired percentage of openness in the interstices between the fabric layers. Uniform openness, as herein defined, is provided in the, or each of the said cell(s) of the humidification chamber.

[0029] Openness, in the context of the present invention, means open space available in the direction of air flow through the cell, i.e. total face area through which air passes, less the thickness of the fabric devided by the face area.

[0030] Evaporative area, in the context of the present invention, means the area defined within each pair of the fabric layers, as and when the said fabric layers are caused to be kept wet continuously, and thereby air/water contact is caused in the event of air being passed along the said wetted fabric area, the area being considered as a smooth flat surface of the fabric and not the extended area as created by individual fibres on the surface of the texturised yarn that forms the fabric.

Description of the drawings :

[0031] The nature and scope of the invention will be better understood from the following description, set out by way of illustration, but not by way of limitation, with reference to the accompanying drawings, wherein :

Fig. 1 shows, in elevation, a particular embodiment of the cell type air humidification system, according to the present invention;
Fig. 2 is an end-view of the same embodiment taken along "A-A" of Fig. 1;
Fig. 3 is a plan of the same embodiment along "B-B" of Fig. 1;
Fig. 4 is a plan of a cell used in the embodiment of the system according to this invention, as shown in Figures 1 to 3;
Fig. 5 shows the cell of Fig. 4, in elevation; and
Fig. 6 shows the details of the fabric arrangement in the cell, in magnified view, in a particular portion marked "D" in Fig. 5.

[0032] As shown in the drawings the cell type air humidification system, according to this invention, comprises a humidification chamber, marked by "H", in general, and said humidification chamber is constituted by a number of cells marked "C". There is also provided in the system means for providing continuous supply of water onto the said humid-

ification chamber, as will be described hereinafter. That apart, means, to be described hereinafter, for blowing/ sucking air, through the said humidification chamber, is also provided.

[0033] As can be seen from Figures 3, 4, 5 and 6, each cell has vertically disposed and uniformly spaced layers of fabrics 9 housed in a rectangular frame, indicated by 7, made of M.S. angles 6. The cells are arranged and fitted in the system by means of supporting angles 8, as shown in Figs. 1 and 3. As described hereinbefore, the fabrics are of non-hygroscopic, non-cellulosic, non-biodegradable material, which is duly processed in the manner, as herein described, e.g. by way of texturising the multifilament yarns of the fabric, so that the fabric made out of the same possesses bulkiness, good water holding capacity, absorbency, spreading and wetting characteristics.

[0034] The humidification chamber is caused to be provided with continuous supply of water by sprayers 3 connected to a main water supply line indicated by 10 and branch pipe lines indicated by 11, and standby pipe and sprayers 18, said water supply line being connected to a pump 1. Valves provided in the lines are indicated by 2 while the pressure gauge and the pot filter are indicated by 4 and 5 respectively. As particularly shown in Figs. 1 and 2, water collecting tank T is disposed below the humidification chamber of the system, for collecting the water sprayed onto the fabrics of the cells suitably fixed in the humidification chamber. The pump 1, as shown, is connected to the tank T through a recirculating line 13 so that the water so collected in the tank T can be recirculated and sprayed through the water spraying arrangement as aforesaid, on to the cell fabrics.

[0035] The fabric layers, as shown, are uniformly spaced, and rods 12 are provided e.g. by way of welding to the frame of the cell, for supporting the fabric layers as shown, in detail, in Fig. 6. Fabric tightening rods indicated by 17 in Fig. 5, are provided for the purpose of tightening the fabric layers, as and when needed.

[0036] Air straightener 16 (as described hereinbefore in detail) and water stripping device 14 (as described hereinbefore in detail) are also provided, as can be clearly seen from Fig. 3. The water collecting tank T(sump), at the bottom of the humidification chamber, is provided with overflow pipe 15. The air flow is indicated by the arrow X.

[0037] The following advantageous results and achievements have been found, on experimentation of the system according to this invention :

a) With sufficient evaporative area for effective heat and mass transfer between air and water, being provided by wetted fabric, high level of %RH of 92-94% of delivery air is achieved. This is with high degree of openness of 97-98% in given space from which air flows over it with minimum drop of static pressure of about 3.3 to 4.7 kPa (7 to 10 mm of water) in comparison of about 9.4 - 15.9 kPa (20-25mm) with STAW. The uniform openness throughout the cell depth minimises the choking of the cells by fluff etc.

b) The fabric which is provided as evaporative area is made of special material such as polyester texturised filaments having high tenacity which is by nature non-hygroscopic but due to its special texturising process the water can be retained between the interstitial space between the fibres. Thus, it can provide good water holding capacity, absorbency, spreading and wetting characteristics, essential to obtain high degree of %RH of delivery air. The fabric is in grey form and desized, and, moreover, as it is non-cellulosic, it is nonbiodegradable in water. Consequently, it can maintain good strength over time and hence long life. It is also cheaper compared with other technically acceptable materials.

c) The fabric material has acid resistance, i.e. any deposition of scale, dirt, fluff etc. can be removed with dilute HCL (1-5%) acid and fresh water wash. After this simple chemical treatment, fabric gets its original form.

d) The arrangement of vertical layers of fabric helps for better and quick spreading of water particle. It also helps in removal of dirt particle/black strick/fluff etc. due to vertical layers wetted with water. Slight inclination helps for better utilisation i.e. absorbing by the fabric instead of directly falling into tank. The fabric layers are used as not only evaporator but also a air straightener and water stripper, per se.

e) For higher degree of saturation of air i.e. RH of the degree 92-94%, the recirculation of tank water is necessary as the water temperature goes down to outside wet bulb temperature (WB) while this is not possible with once-through system, wherein fresh water is sprayed and run-down water from the cell is drained continuously.

f) The fabric layers are tightened enough so that these do not stick with each other resulting in reduction in effective evaporative area. Moreover due to its tightness, these do not get flapped due to air flow, and, as a result, strength of fabric does not reduce due to frequent expansion and contraction. Further, the selvages of the fabric do not allow it to be torn. The tightness of fabric layer also presents the fabric from slipping over the SS rods on which these are supported, along with the direction of air flow. The tightening is approximately 4.9 to 9.8 N/cm (1/2 to 1 kg/cm) width of cloth width measured over the rod.

g) The fabric cells can be used in both sucked through or blow through air system i.e. the fan is before the air washer, blowing the air over the cell and vice versa.

h) The fabric cells give sufficient time to get the air saturated, at air velocity of 2.5-2.75 m/sec, arrived from air flow divided by net area of chamber minus area occupied by the frames of cells.

i) The bypass system helps to control the water flow according to season i.e. less evaporation of water in humid season. So, less water recirculation is required, and by opening more bypass valves, water recirculation can be

reduced and there is no carry over of water particles, because excess water is bypassed.
j) The stand by spraying arrangement helps when some of the regular nozzles are not functioning properly so that additional water can be sprayed by standby spraying system near the top of the top most cell.
k) Water is preferably continuously sprayed over the fabric cell to avoid the drying and wetting of fabric, which, otherwise, results in deposition of salts/scale on fabric layers.
l) Continuous overflow of water helps in maintaining low TDS (total dissolved solids) in tank water. Before start of the plant, the tank should be completely cleaned with fresh water.
m) Decrease in water recirculation is caused by about 1/10th as compared with the existing STAW, and pumping power is reduced by 1/10th. So pumping power consumption is reduced by 80-90% in comparison to that of STAW.
n) Due to less resistance to air flow upto about 35% fan power is also saved in comparison to that of STAW.
o) Cell design provides optimum surface area so that required adiabatic performance is obtained
p) The design of the air washer- is so chosen that it can be retrofitted in the existing air washer and can also be fixed in the new plants. The design of the air washer is such that it can be fabricated in most of the general purpose workshop that does not need any expensive and sophisticated equipments.

Claims

1. A cell type air humidification system for industrial purpose, comprising a humidification chamber (H), means for providing continuous supply of water onto the said humidification chamber (H), and means for blowing/sucking air through the said humidification chamber (H), said humidification chamber (H) being constituted by one or more cells (C), the said cell (C) or each of the said cells (C) having vertically disposed and uniformly spaced layers of material (9), housed in a rectangular frame (7), whereby the required extensive wetted area, with high degree of openness to air flow is caused to be provided for effective heat and mass transfer between the moving air and the water, said material being of the non-hygroscopic, non-cellulosic and non-bio-degradable type, characterized by the layers of material being fabric layers and the air being caused to move over the wet surface along the width of the fabric layers, which substantially conforms to the depth of the said cell (C) or each of the said cells (C), said fabric (9) having the properties of good water holding capacity, absorbency, spreading and wetting characteristics, all of which being essential to enable highly effective saturation of large volume air stream at high velocity, the said fabric (9) being made of Nylon, polyester, polypropylene filaments/yarns/fibres, glass fibres and the like, duly processed by texturising along with twisting configuration for providing appropriate geometry of the fabric (9) to achieve the said characteristics, and further the said fabric (9) being of selected multi-fibre or multi-filament yarn, instead of mono-filament type of yarn configuration, to impart the said characteristics to the fabric (9).

2. A system according to claim 1, characterized in that, the fabric (9) is in the grey form and desized.

3. A system according to claim 1 or 2, characterized in that the means for providing continuous supply of water comprises a water spraying arrangement, disposed at one side of said cell (C) or each of the said cells (C) of the humidification chamber (H), said water spraying arrangement being constituted by a plurality of nozzles (3) for spraying water onto the fabric layers, concurrently with air flow, and being connected to a water supply line (10), a water collecting tank (T) disposed at the bottom of the humidification chamber (H), and a water pump (1) for supplying water, under required pressure, to the said water supply line (10), and, if desired, said water pump (1) having connection with the said water collecting tank (T) for recirculation of the collected water and spraying thereof onto the humidification chamber (H).

4. A system according to any of the preceding claims, characterized in that the humidification chamber (H) is provided with air straighteners (16) constituted by vertically disposed louvres, said louvres being disposed and/or adapted to be moved such as to cause entry of air into the humidification chamber (H) in straight manner without any turbulence.

5. A system according to any of the preceding claims, characterized in that the humidification chamber (H) is provided with water stripping device (14) constituted by one or more layer(s) of non-corrosive materials, said layer(s) being disposed downstream the said cell (C) or each of the said cells (C) of the humidification chamber (H), whereby air borne water is caused to be removed.

6. A system according to claim 7, characterized in that the said layer or layers constituting the water stripping device (14) is(are) of "V" shape for causing sharp turn of air-flow passing through the same, whereby free water suspended in the air is caused to be removed from the air.

7. A system according to any of the preceding claims, characterized in that the fabric layers of said cell (C) or each of the said cells are held in the rectangular frame by means of rods (17) of non-corrosive material, laterally provided at the top and bottom end of the frame (7), said rods (17) being adapted to be used for support of the fabric (9), wrapped over the same in successive manner, and also for tightening/loosening, the fabric (9) as and when desired, according to requirement.

8. A system according to any of claims 3 to 7, characterized in that the water supply line of the spraying arrangement is provided with filter(s)/pot-strainer (5) for supply of filtered water onto the humidification chamber (H).

9. A system according to claim 8, characterized in that water cleaning/descaling arrangement is provided for supply of clean water, through the water spraying arrangement, onto the humidification chamber (H).

10. A system according to claim 8 or 9, characterized in that the water supply line of the spraying arrangement is provided with by-pass arrangement for desired control of water flow.

11. A system according to any of claims 8 to 10, characterized in that a stand-by spraying arrangement is provided in combination with the said water spraying arrangement for use thereof in continuous supply of water onto the humidification chamber (H), in the event of failure of the said water spraying arrangement, or for its stoppage during maintenance.

12. A system according to any of the preceding claims, characterized in that the width of the fabric layers is minimum 90 cm (3 ft).

13. A system according to claim 12, characterized in that, the spacing between the fabric layers is determined, depending on the desired evaporative area, and desired percentage of openness in the interestices between the fabric layers.

14. A system according to any of the preceding claims, characterized in that uniform openness with respect to air flow imposed by the cell or cells (C) is provided to avoid channelling effect in the said cell (C) or each of the said cells (C) of the humidification chamber (H).

Patentansprüche

1. Zellartige Luftbefeuchtungsanlage für industrielle Anwendung, mit einer Befeuchtungskammer (H), einer Einrichtung, um die Befeuchtungskammer (H) kontinuierlich mit Wasser zu versorgen, und einer Vorrichtung, um Luft durch die Befeuchtungskammer (H) zu blasen/saugen, wobei die Befeuchtungskammer (H) aus einer Zelle oder mehreren Zellen (C) besteht, wobei die Zelle (C) oder jede der Zellen (C) vertikal angeordnete und gleichförmig beabstandete Materiallagen (9) in einem rechteckigen Rahmen (7) aufweist, wodurch die erforderliche, ausgedehnte, feuchte Fläche, mit hohem Durchlässigkeitsgrad für die Luftströmung erzielt wird, für einen wirksamen Wärme- und Masseübergang zwischen der Luftströmung und dem Wasser, und das Material nicht-hygroskopisch, nicht-zellulosisch, nicht-biologisch abbaubar ist, dadurch gekennzeichnet, daß die Materiallagen Gewebelagen sind, und die Luft veranlaßt wird über die feuchte Fläche zu strömen längs der Breite der Gewebelagen, welche im wesentlichen der Tiefe der Zelle (C) oder jeder der Zellen (C) entspricht, wobei das Gewebe (9) die Eigenschaften eines guten Wasserhaltevermögens, Absorbierfähigkeit, Verteilungs- und Befeuchtungsfähigkeit aufweist, welche alle wesentlich sind, um eine hochwirksame Saturation eines großvolumigen Luftstroms mit hoher Geschwindigkeit zu erzielen, und wobei das Gewebe (9) aus Nylon-, Polyester-, Polypropylenfilamenten/fäden/fasern, Glasfasern und dergleichen bestehen, die ordnungsgemäß behandelt sind durch Strukturierung zusammen mit Torsionsgestaltung zur Erzielung einer geeigneten Geometrie des Gewebes (9), um die besagten Eigenschaften zu erzielen, und wobei desweiteren das Gewebe (9) aus ausgewählten Vielfaser oder Vielfilamentfäden bestehen, anstatt der Gestaltung aus einem Monofilamentfaden, um dem Gewebe (9) die besagten Eigenschaften zu verleihen.

2. Anlage nach Anspruch 1, dadurch gekennzeichnet, daß das Gewebe ungebleicht und entschlichtet ist.

3. Anlage nach Anspruch 1 oder 2, dadurch gekennzeichnet, daß die Wasserversorgungseinrichtung eine Wassersprühanlage aufweist, die sich auf einer Seite der Zelle (C) oder jeder der Zellen (C) der Befeuchtungskammer (H) befindet, wobei die Wassersprühanlage aus einer Mehrzahl von Düsen (3) besteht, zum Sprühen von Wasser

auf die Gewebelagen, gleichzeitig mit der Luftströmung, welche an eine Wasserzufuhrleitung (10) angeschlossen sind, einen Wassersammelbehälter (T) am unteren Ende der Befeuchtungskammer (H), und eine Wasserpumpe (1) zum Einspeisen von Wasser, unter dem erwünschten Druck, in die Wasserzufuhrleitung (10), und, falls erwünscht, eine Verbindung zwischen der Wasserpumpe (1) und dem Wassersammelbehälter (T) zum Umwälzen des angesammelten Wassers und Sprühen desselben in die Befeuchtungskammer (H).

4. Anlage nach einem der vorhergehenden Ansprüche, dadurch gekennzeichnet, daß die Befeuchtungskammer (H) mit Luftgleichrichtern (16) versehen ist, welche aus vertikal angeordneten Leitflächen bestehen, wobei die Leitflächen angeordnet und/oder einstellbar sind, damit die Luft in gerader Richtung ohne jede Turbulenz in die Befeuchtungskammer (H) einströmt.

5. Anlage nach einem der vorhergehenden Ansprüche, dadurch gekennzeichnet, daß die Befeuchtungskammer (H) mit einer Wasserabscheidevorrichtung (14) versehen ist, welche aus einer Lage oder mehreren Lagen aus nichtkorrosivem Werkstoff besteht, wobei die Lage oder Lagen stromabwärts der Zelle (C) oder jeder der Zellen (C) der Befeuchtungskammer (H) vorgesehen sind, damit in der Luft mitgeführtes Wasser abgeschieden wird.

6. Anlage nach Anspruch 5, dadurch gekennzeichnet, daß die Lage oder Lagen, welche die Wasserabscheidevorrichtung (14) bilden, eine V-förmige Form aufweist bzw. aufweisen, um eine scharfe Umlenkung der Luftströmung durch die Abscheidevorrichtung zu bewirken, wodurch freies, in der Luft mitgeführtes Wasser aus dem Luftstrom abgeschieden wird.

7. Anlage nach einem der vorhergehenden Ansprüche, dadurch gekennzeichnet, daß die Gewebelagen der Zelle (C) oder einer jeden der Zellen (C) in dem rechteckigen Rahmen zurückgehalten werden mittels Stangen (17) aus nichtkorrosivem Material, die sich seitlich erstrecken am oberen Ende und am unteren Ende des Rahmens (7), wobei die Stangen (17) zum Tragen des Gewebes (7) dienen, das in aufeinander folgender Weise über die Stangen geführt ist, sowie auch zum Spannen/Lockern des Gewebes (9) wie und wann gewünscht, je nach Bedarf.

8. Anlage nach einem der Ansprüche 3 bis 7, dadurch gekennzeichnet, daß die Wasserzufuhrleitung der Sprühanlage mit einem oder mehreren Filtern/Filtriertöpfen (5) versehen ist zum Zuführen von filtriertem Wasser in die Befeuchtungskammer (H).

9. Anlage nach Anspruch 8, dadurch gekennzeichnet, daß eine Reinigungs/Entkalkungseinrichtung vorgesehen ist zum Zuführen von gereinigtem Wasser, durch die Wassersprühanlage, in die Befeuchtungskammer (H).

10. Anlage nach Anspruch 8 oder 9, dadurch gekennzeichnet, daß die Wasserzufuhrleitung der Sprühanlage mit einer Umgehungsvorrichtung versehen ist zur erwünschten Steuerung der Wasserströmung.

11. Anlage nach einem der Ansprüche 8 bis 10, dadurch gekennzeichnet, daß eine Reservesprühanlage vorgesehen ist in Verbindung mit der Wassersprühanlage zur Benutzung derselben zur kontinuierlichen Wasserversorgung der Befeuchtungskammer (H), wenn die Wassersprühanlage ausfällt oder für die Wartung stillgesetzt wird.

12. Anlage nach einem der vorhergehenden Ansprüche, dadurch gekennzeichnet, daß die Breite der Gewebelagen minimal 90 Zentimeter (3 Fuß) aufweist.

13. Anlage nach Anspruch 12, dadurch gekennzeichnet, daß der Abstand zwischen den Gewebelagen bestimmt ist, in Abhängigkeit der erwünschten Verdampfungsfläche, und des erwünschten Prozentsatzes der Durchlässigkeit in den Zwischenräumen zwischen den Gewebelagen.

14. Anlage nach einem der vorhergehenden Ansprüche, dadurch gekennzeichnet, daß eine gleichförmige Durchlässigkeit hinsichtlich der durch die Zelle oder die Zellen (C) auferlegten Luftströmung erzielt wird, um einen Kanaleffekt in der Zelle (C) oder einer jeder der Zellen (C) der Befeuchtungskammer (H) zu vermeiden.

Revendications

1. Système d'humidification d'air du type cellulaire destiné à l'usage industriel, comportant une chambre d'humidification (H), un moyen pour prévoir une alimentation continue d'eau vers la chambre d'humidification (H), et un moyen pour souffler/aspirer de l'air à travers la chambre d'humidification (H), cette chambre d'humidification (H)

étant constituée par une ou plusieurs cellules (C), ladite cellule (C) ou chacune de ces cellules (C) ayant des couches de matériau (9) disposées verticalement et espacées uniformément, encastrées dans un cadre rectangulaire (7), de sorte que la surface humidifiée étendue exigée, avec un degré élevé de pénétrabilité offert au courant d'air soit obtenu pour un transfert efficace de chaleur et de matière entre le courant d'air et l'eau, ce matériau étant du type non-hygroscopique, non-cellulosique et non-biodégradable, caractérisé en que les couches de matériau sont des couches de tissu et en ce que l'air est causé de s'écouler pardessus de la surface humidifiée le long de la largeur des couches de tissu, qui correspond sensiblement à la profondeur de ladite cellule (C) ou chacune des cellules (C), ce tissu (9) ayant les caractéristiques d'une bonne capacité de retenue d'eau, d'absorption et propriétés de distribution et d'humidification, toutes ces caractéristiques étant essentielles pour permettre une saturation hautement efficace d'un courant d'air de volume élevé à haute vitesse, ledit tissu (9) étant fabriqué de filaments/fils/fibres en Nylon, polyester, polypropylène, et fibres de verre ou pareils, dûment traités par texturation ensemble avec une configuration tordue afin de prévoir une géométrie appropriée du tissu (9) pour obtenir lesdites caractéristiques, et le tissu (9) étant en outre fabriqué d'un fil sélectionné multi-fibres ou multi-filaments, au lieu d'une configuration à fil du type mono-filament, pour donner lesdites caractéristiques au tissu (9).

2. Système selon la revendication 1, caractérisé en ce que le tissu (9) est en état écru et désencollé.

3. Système selon la revendication 1 ou 2, caractérisé en ce que le moyen pour prévoir une alimentation continue d'eau comporte un ensemble d'arrosage d'eau, disposé à l'un des côtés de la cellule (C) ou de chacune des cellules (C) de la chambre d'humidification (H), l'ensemble d'arrosage d'eau étant constitué par une pluralité de gicleurs (3) pour asperger de l'eau sur les couches de tissu, simultanément avec le courant d'air, et connectés à une conduite d'alimentation d'eau (10), un réservoir d'eau (T) disposé en bas de la chambre d'humidification (H), et une pompe d'eau (1) pour refouler l'eau, sous la pression requise, vers la conduite d'alimentation d'eau (10), et, si désiré, la pompe d'eau (1) étant raccordée au réservoir d'eau (T) pour récirculation de l'eau s'accumulant dans le réservoir et en vue de l'asperger sur la chambre d'humidification (H).

4. Système selon l'une quelconque des revendications précédantes, caractérisé en ce que la chambre d'humidification (H) est pourvue d'un redresseur (16) du courant d'air, constitué par des volets disposés verticalement, ces volets étant disposés et/ou conçus en vue d'être orientés de façon à assurer l'entrée de l'air dans la chambre d'humidification (H) de façon linéaire sans aucune turbulence.

5. Système selon l'une quelconque des revendications précédantes, caractérisé en ce que la chambre d'humidification (H) est pourvue d'un dispositif de séparation d'eau (14) constitué par une ou plusieurs couches de matériau non-corrosif, cette ou ces couches étant disposée(s) en aval de ladite cellule (C) ou de chacune de ces cellules (C) de la chambre d'humidification (H), pour séparer l'eau emporté par le courant d'air.

6. Système selon la revendication 5, caractérisé en ce que la couche ou les couches constituant le dispositif de séparation d'eau (14) est (sont) en forme de V de façon à provoquer un changement de direction soudain du courant d'air passant par le dispositif de séparation, pour séparer du courant d'air des gouttes d'eau libres emportées par le courant d'air.

7. Système selon l'une quelconque des revendications précédantes, caractérisé en ce que les couches de tissu de ladite cellule (C) ou de chacune des cellules (C) sont retenues dans le cadre rectangulaire au moyen de tiges (17) en matière non-corrosive, s'étendant latéralement en haut et en bas du cadre (7), ces tiges (17) étant prévues pour supporter le tissu (9) passant de façon successive autour des tiges, et aussi pour tendre/relâcher le tissu (9), si, et quand l'on le désire, selon les besoins.

8. Système selon l'une quelconque des revendications 3 à 7, caractérisé en ce que la conduite d'alimentation d'eau de l'ensemble d'arrosage est pourvue d'un ou plusieurs filtres/pots de filtrage (5) pour alimenter de l'eau filtrée vers la chambre d'humidification (H).

9. Système selon la revendication 8, caractérisé en ce qu'un ensemble de nettoyage/détartrage est prévu pour fournir de l'eau propre, par l'ensemble d'arrosage, dans la chambre d'humidification (H).

10. Système selon la revendication 8 ou 9, caractérisé en ce que la conduite d'alimentation d'eau de l'ensemble d'arrosage est pourvue d'un système de dérivation pour réglage désiré du courant d'eau.

11. Système selon l'une quelconque des revendications 8 à 10, caractérisé en ce qu'un ensemble d'arrosage de

réserve est prévu en combinaison avec l'ensemble d'arrosage d'eau en vue d'assurer une alimentation continue d'eau vers la chambre d'humidification (H), dans le cas d'une panne de l'ensemble d'arrosage d'eau, ou pendant son arrêt en vue de l'entretien.

12. Système selon l'une quelconque des revendications précédantes, caractérisé en ce la largeur des couches de tissu est au moins 90 cm (3 pieds).

13. Système selon la revendication 12, caractérisé en ce que l'écartement entre les couches de tissu est déterminé en fonction de la surface d'évaporation désirée, et du pourcentage désiré de pénétrabilité dans les interstices entres les couches de tissu.

14. Système selon l'une quelconque des revendications précédantes, caractérisé en ce qu'une pénétrabilité uniforme pour le courant imposé par la cellule ou les cellules (C) est prévue en vue d'empêcher l'effet de canalisation dans ladite cellule (C) ou chacune des cellules (C) de la chambre d'humidification (H).

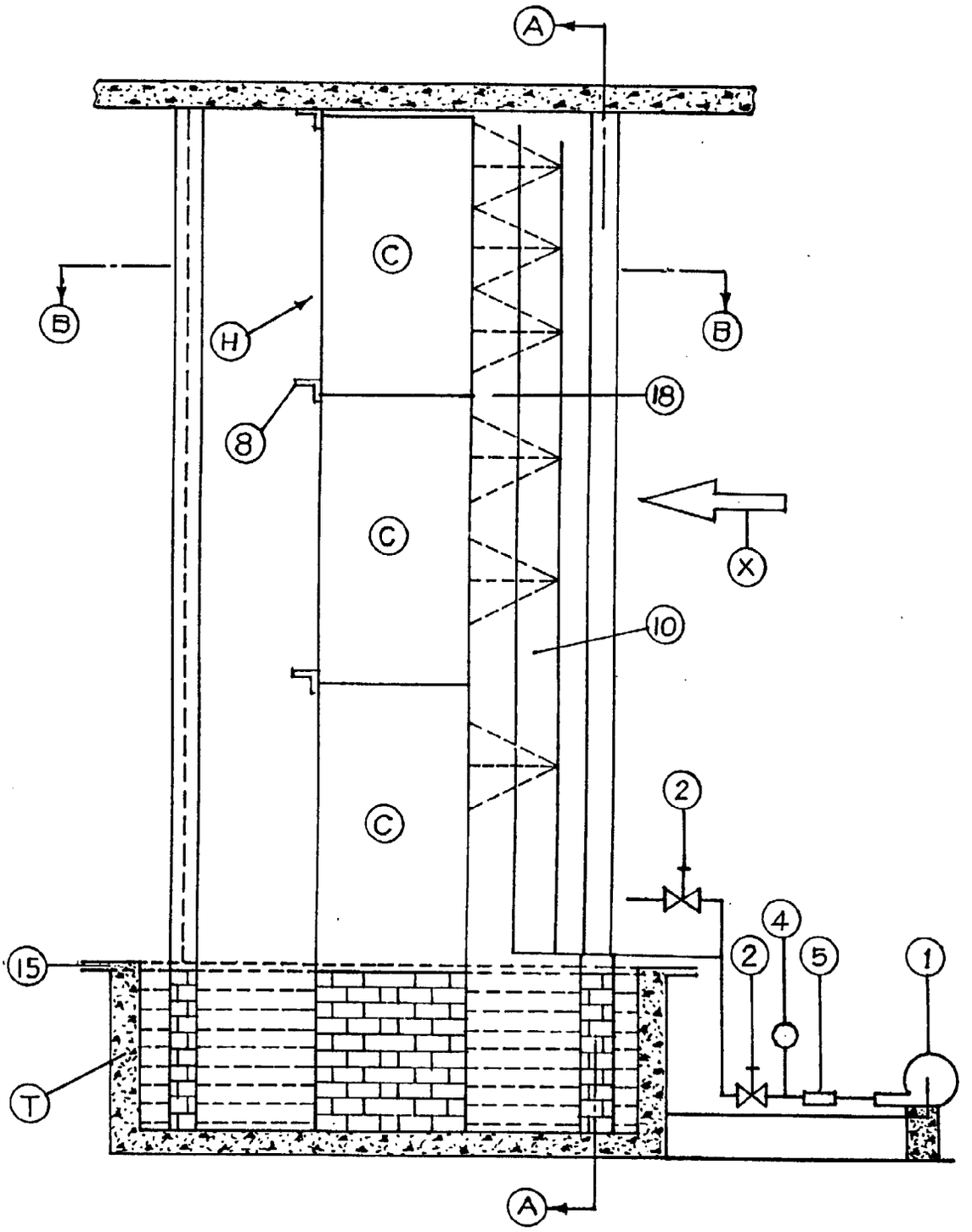

FIG. 1.

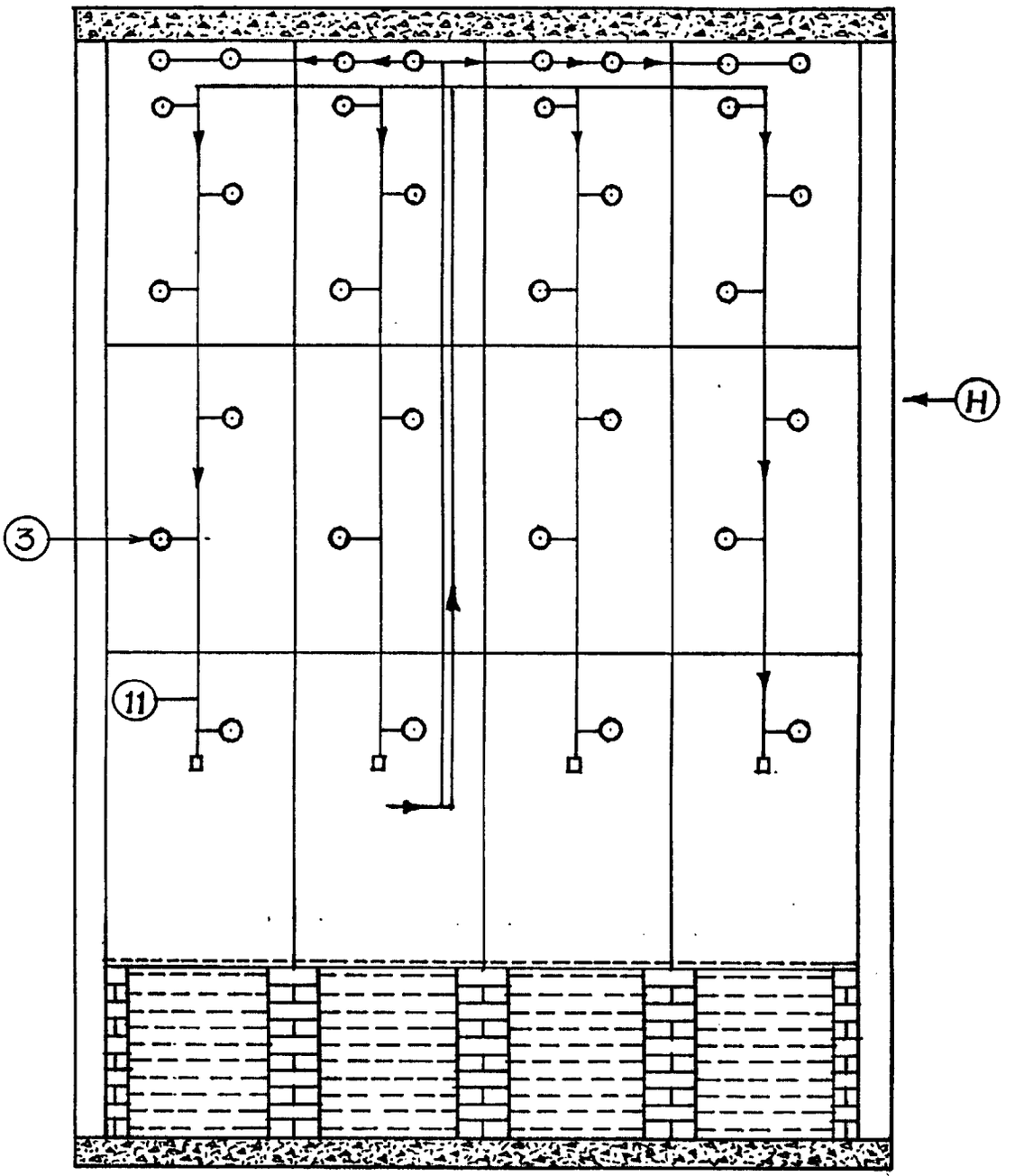

FIG. 2.

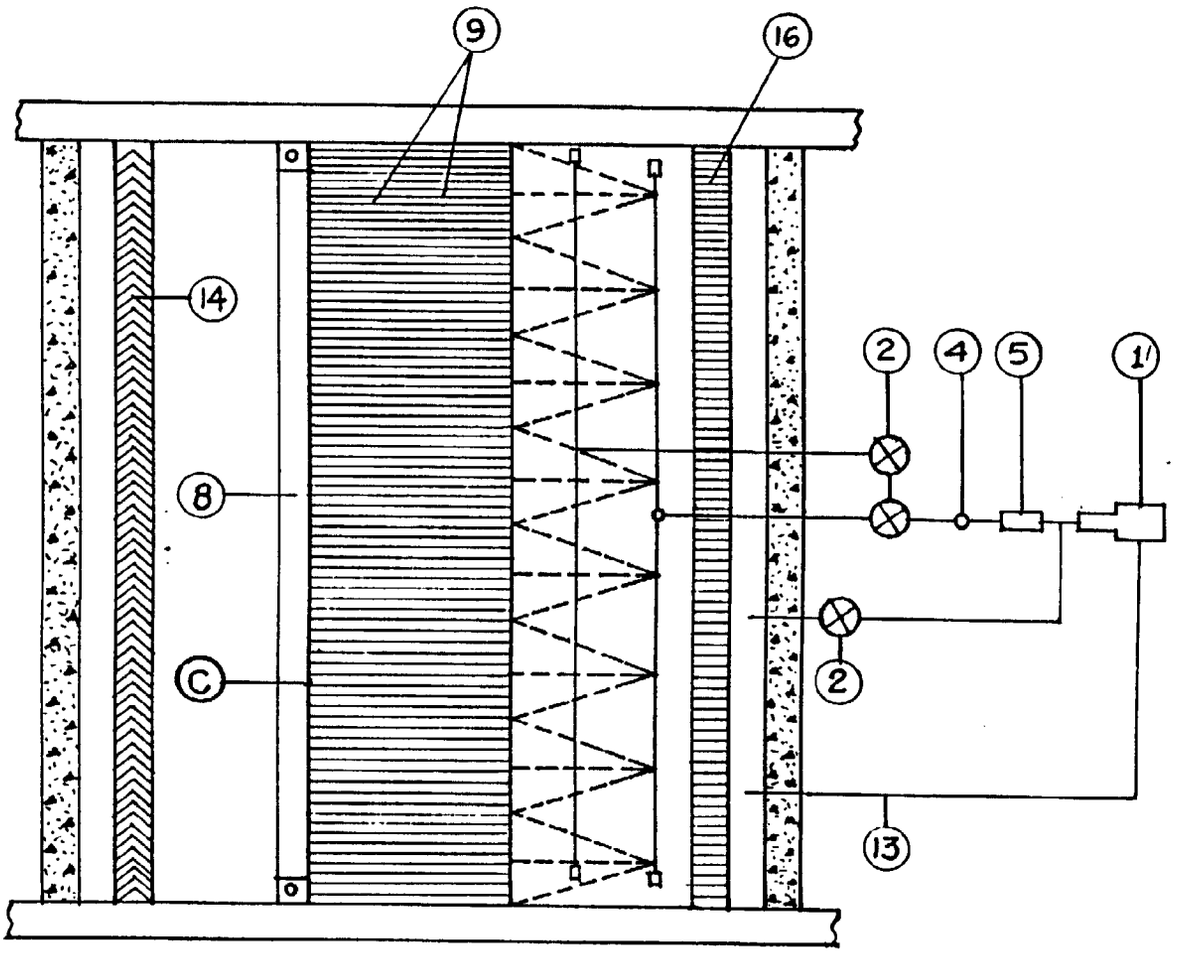

FIG. 3.

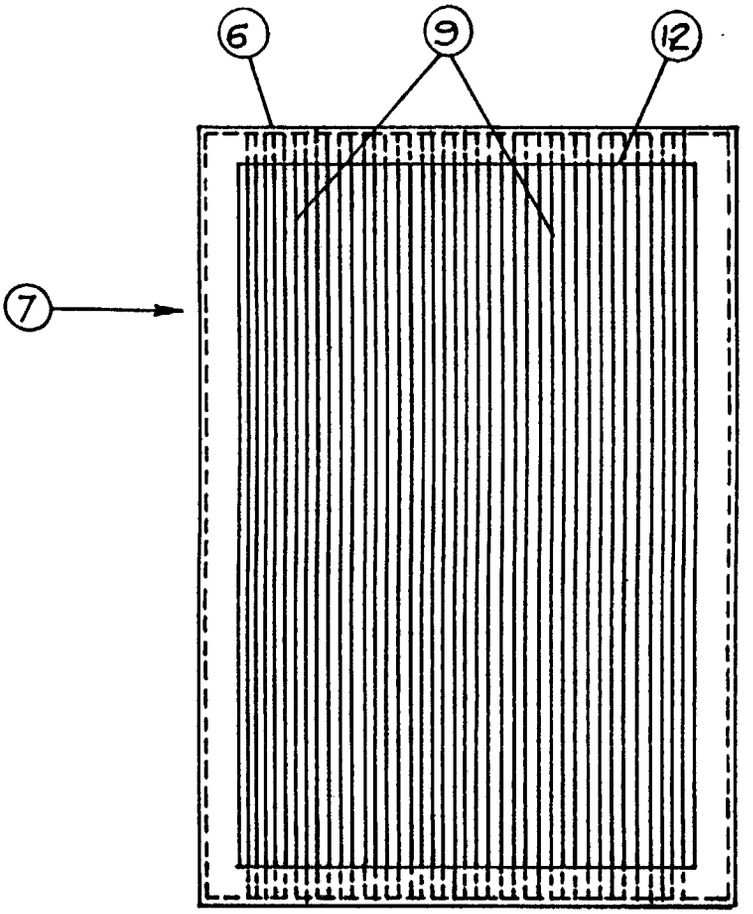

FIG. 4.

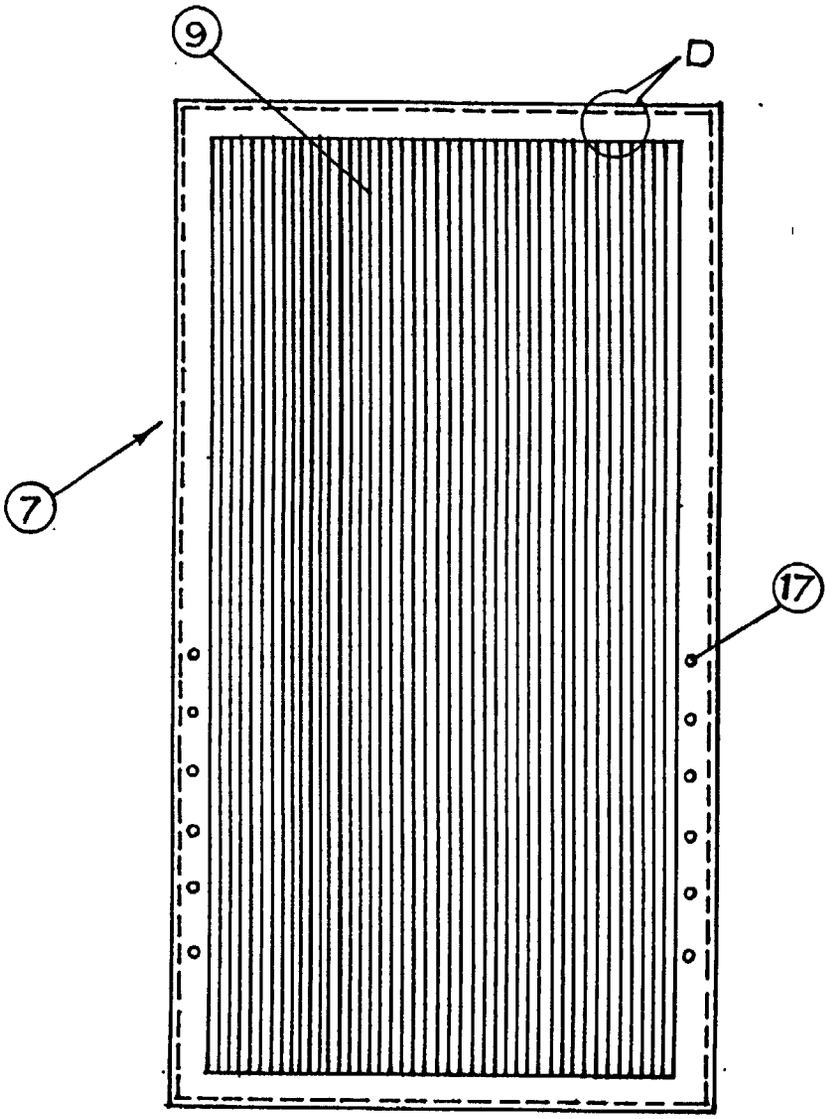

FIG. 5.

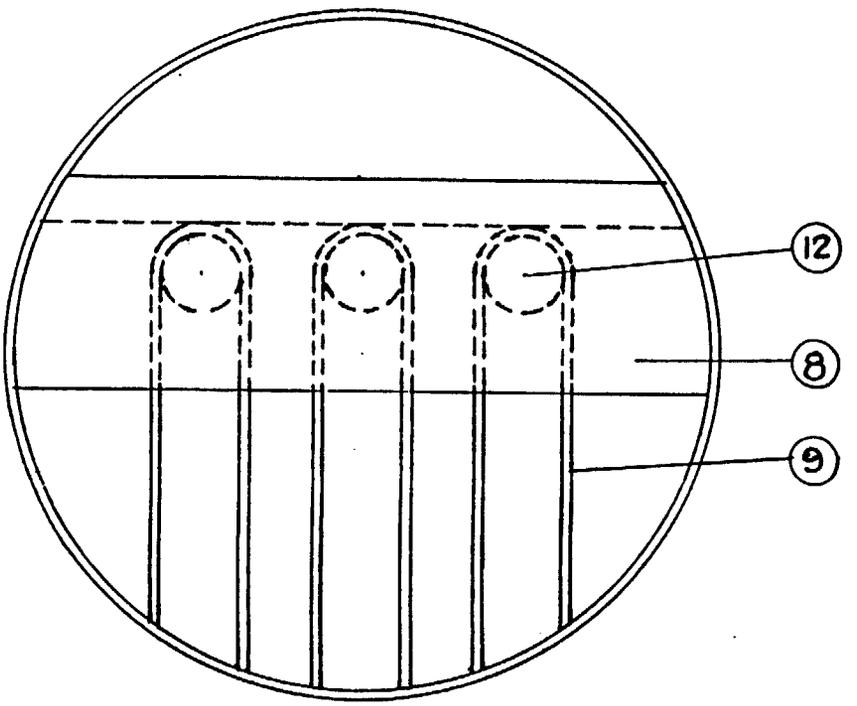

FIG. 6.