IOP Conference Series: Materials Science and Engineering

Improvement of design and calculation method for contact air humidifiers

To cite this article: A G Averkin *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **483** 012041

Improvement of design and calculation method for contact air humidifiers

A G Averkin, A I Yeremkin, T I Korolyova, K O Chichirov and S O Kiselyov

Penza State University of Architecture and Construction, 28 German Titov Street, Penza, 440028, Russia

E-mail:algraw@mail.ru

Abstract. Described are designs, principle of operation and calculation technique for contact-type water-cooled air humidifiers in air conditioning systems. Presented is a range of rotor-type and film-type contact apparatuses working in adiabatic air humidification conditions. The said equipment has been devised as a result of experimental investigation in the University and is characterized with reduced specific consumption of materials, power and cost. Positive results are achieved by increasing the time of working media contact in the process of heat-mass trans fer and increase in heat-mass transfer area. A procedure has been devised to calculate the heat-mass transfer area, based on application of humid air I-d-diagram and number of transfer units which is determined by graphic integration method.

1. Introduction.

An artificial air humidification mainly in the cold period of year is a prerequisite for creating comfortable air conditions in rooms, as well as providing micro climatic parameters meeting specific requirements of modern technological processes practically in all regions of Russia [1].

To humidify air in air-conditioning systems (ACS), contact heat-and-mass exchangers are used. In the exchangers air flow contacts water directly.

Variety of types of contact apparatuses produced for hygrothermal air conditioning is accounted for by various ways for creating a phase interface in working fluids.

To humidify and cool air adiabatically, water is used whose temperature should equal wet bulb air temperature. For this purpose, water is to be circulated in the contact apparatus (Figure 1) [1]- [4].

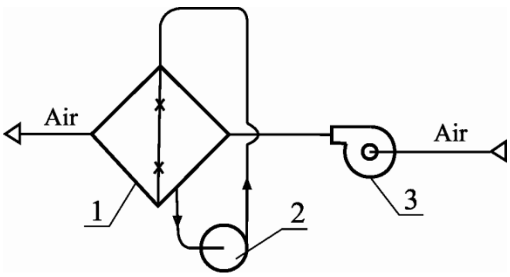

Figure 1. Diagram of contact apparatus with water Recirculation 1 – contact apparatus; 2 – water pump; 3 – fan

2. Basic part

To allow engineering modification aimed at reducing consumption of materials, power and cost of contact apparatuses for adiabatic humidification of air, a range of rotor-type and film-type contact apparatuses (Figures 2, 3, 4) has been devised at the University department “Heat and Gas Supply and Ventilation”.

The contact apparatus of rotor-type (Figure 2, RF Patent 2270958) is composed of an air washer whose lower part has a water-collecting sump. Inside the air washer, there is a cruciform turbine with its horizontal shaft.

The lower part of the blades is immersed in water by some millimeters. At the chamber inlet, there are guide plates that allow changing air flow direction with regard to the turbine blades and controlling the turbine speed in a unit time, whereas at the outlet there is a drop catcher that prevents entrainment of liquid particles with air flow. A centrifugal fan is attached to the chamber end face through a flexible duct connector.

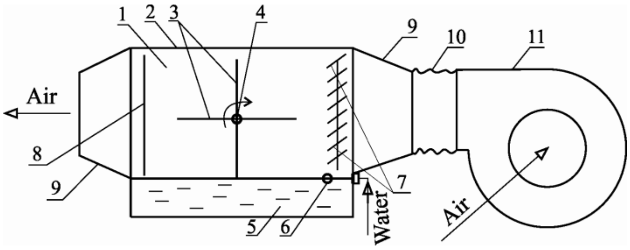

Figure 2. Diagram of spinning disk humidifier 1 – air channel; 2 – chamber; 3 – turbine blades; 4 – axle; 5 – water sump; 6 – float; 7 – guide plates; 8 – drop catcher; 9 – branch pipes; 10 – flexible duct connector; 11 – fan.

The device works as follows. The centrifugal fan delivers air to the chamber. At that time, the cruciform turbine starts rotating under the dynamic pressure of air flow and friction forces. During rotation the lower part of the turbine blades throws out part of liquid onto air flow and neighboring blades, i.e. water is sprayed in air and at the same time the blade hygroscopic material (gauze) is becoming moist. Air becomes wet due to evaporation of some sprayed water particles and film-type contact of air flow with the wet hygroscopic material of the cruciform turbine blades. Non-evaporated water droplets fall down back to the water sump, i.e. aqueous phase recirculates in the chamber. Its temperature stabilizes at a level of wet bulb air temperature.

Hygrothermal air conditioning takes place when air flows horizontally along the chamber thanks to the centrifugal fan operation.

This contact unit is notable for its compactness and less power consumption because it has neither turbine drive mechanism nor water recirculation pump. The unit is the most adaptable to operate in ducted ventilation and air conditioning systems.

Another modification of the spinning disc humidifier is represented by the design with air flow recirculation (Figure 3, RF Patent 2294490).

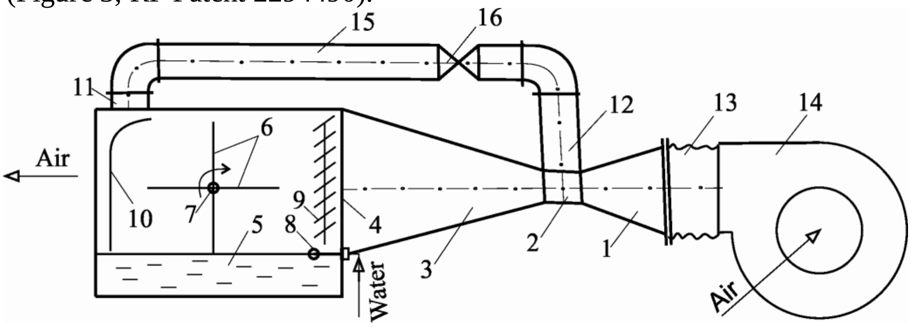

Figure 3. Spinning disk humidifier with air flow recirculation
1 – confuser; 2 – mouth; 3 – diffuser; 4 – chamber casing; 5 – water sump; 6 – turbine; 7 – turbine axis; 8 – float device; 9 – guide plates; 10 – drop catcher; 11, 12 – pipe branches; 13 – flexible duct connector; 14 – fan; 15 – recirculation air duct; 16 – valve

With the help of pipe branches 11, 12 of by-pass air duct 15 the chamber outlet channel is connected to the chamber inlet channel where Venturi tube is located. The Venturi tube consists of confuser 1, mouth 2 and diffuser 3. The Venturi tube is connected to centrifugal fan 14 through flexible duct connector 13. Air flow through by-pass 15 is controlled with the help of valve 16.

When the unit is running, air coming out of chamber 4 is ejected through by-pass air duct 15 into mouth 2 of Venturi tube, i.e. the process of hygrothermal air conditioning goes on with application of humidified air recirculation principle.

Ejection takes place due to reducing air static pressure, increasing air dynamic pressure in the mouth in full conformity with the equation of air flow total pressure:

$$dP_{\text{îëí}} = dP_s + dP_d = dP_s + \frac{\rho v^2}{2}, \quad (1)$$

where $dP_{\text{îëí}}$, dP_s, dP_d – are, respectively, total pressure, static pressure, dynamic pressure of air flow in the mouth section, Pa; ρ – air density, kg/m^3; v – air-flow rate, m/sec.

The principle of recirculating air through a contact apparatus allows increasing the durability of air-aqueous phase contact, which intensifies heat-mass exchange, i.e. enhances the effectiveness of the adiabatic air humidification process. This comes from the convective heat exchange equation (2) and convective mass transfer equation (3) [5]-[7]:

$$d\left(\frac{Q}{F_{\grave{o}}}\right) = dq = \alpha(t_1 - t_2)d\tau, \quad (2)$$

$$d\left(\frac{M}{F_{\grave{i}}}\right) = dj = \beta(d_1 - d_2)d\tau, \quad (3)$$

where Q – is quantity of heat transferred from air flow to water, J; M – is quantity of water vapor coming from water to air flow, kg; $F_{т}$ – is heat exchange area, m^2; $F_{м}$ – is mass exchange area, m^2; dq – is heat flow density differential, J/m^2; α – coefficient of heat transfer from air flow to water, W/(m^2·°C); t_1, t_2 – are, respectively, air flow temperature and water temperature in the contact apparatus, °C; dj – is differential in specific water vapor mass discharge, kg/m^2; β – is coefficient of heat transfer from water to air flow, m/sec; d_1, d_2 – are, respectively, air moisture content in the boundary layer near the water surface and in the air flow, kg/kg; $d\tau$ – is moveout time (duration of heat-mass exchange), sec.

In addition, a contact apparatus with a vibrated plate packing has been devised, manufactured and installed to humidify air (Figure 4, RF Patent 2581982).

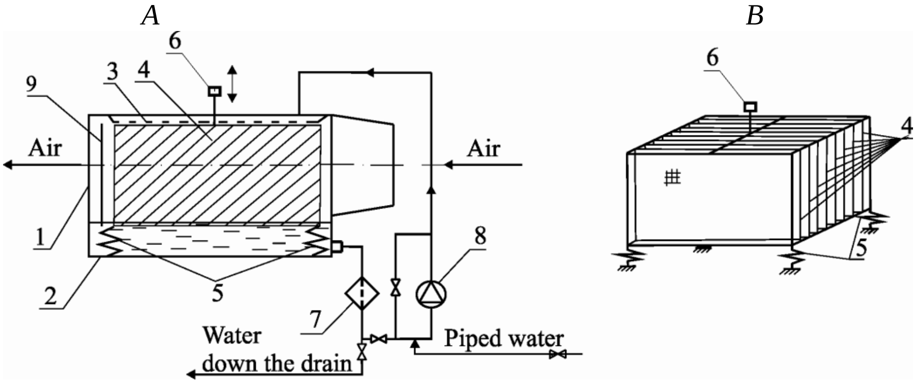

Figure 4. Contact apparatus with vibrated plate packing A – diagram; B – contact assembly with plate packing 1 – casing; 2 – lower tray; 3 – upper perforated tray; 4 – plate packing unit; 5 – spring shock absorber; 6 – mechanical vibrator; 7 – water filter; 8 – pump; 9 – drop catcher

The said apparatus is intended for hygrothermal air conditioning and works as follows.

With the help of a fan (not shown in figure 4) air comes into the humidifying unit of the vibrated plate packing 4. The vibrated plate packing is kept under mechanical vibration due to operation of mechanical vibrator 6 consisting of an eccentric flywheel secured on the motor shaft (not shown in the figure). The plate packing is continuously showered with recirculated water coming from the lower water sump 5 into the upper perforated tray 3 with the help of pump 8.

Water temperature stabilizes at a level of wet bulb air thermometer, i.e. hygrothermal air conditioning meets the adiabatic humidification and cooling mode. Air is moistened thanks to a film-like contact of air flow with packing wet plates made of hygroscopic material (viscose) 4 and in addition due to evaporation of the halo of water droplets and splashes caused by mechanical vibration of the packing wet plates.

The process of heat-mass exchange is intensified by increasing the heat-mass transfer area.

To calculate air-conditioning contact apparatuses, a method using number of transfer units has been prepared [1].

The thermotechnical calculation of contact apparatuses for air-conditioning systems is suggested to be as follows.

1. Set initial data for adiabatic humidification (cooling) of air - t_1, I_1, t_2;
2. Construct the ray of hygrothermal air conditioning process on *I-d* - diagram in accordance with figure 5.

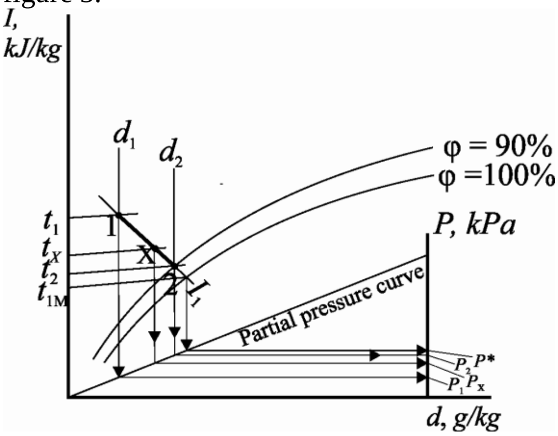

Figure 5. Determination of current and equilibrium values of water temperature as well as current and equilibrium values of water vapor partial pressure under adiabatic air humidification and cooling

3. Determine the number of transfer units n_t, for implementation of heat-exchange processes and the number of transfer units n_p – for mass-exchange processes.

Based on figure 5, plot characteristic curves for adiabatic air humidification (cooling) (Figure 6).

$$\frac{1}{t-t*} = f(t); \quad (4)$$

$$\frac{1}{P^*-P} = f(P); \quad (5)$$

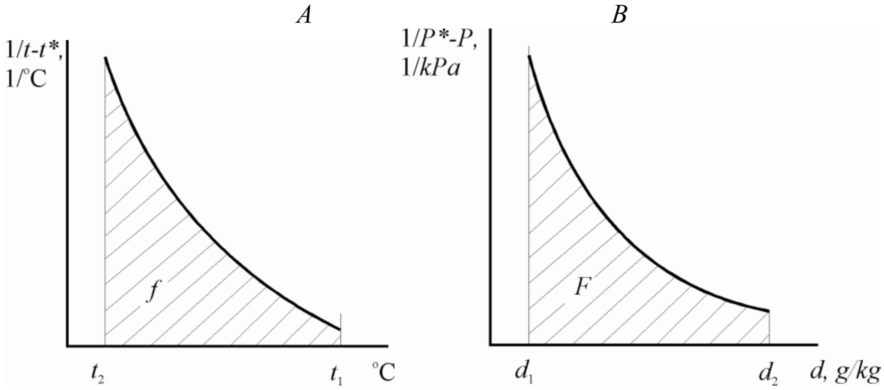

Figure 6. Characteristic curves for determining the number of transfer units

The number of transfer units is calculated from below formulas:

$$n_t = \int_{t_1}^{t_2} \frac{dt}{t-t^*} = f \cdot m_1 \cdot m_2 \ ; \quad (6)$$

$$n_p = \int_{P_1}^{P_2} \frac{d(d)}{P^*-P} = F \cdot M_1 \cdot M_2 \, ; \quad (7)$$

here *t, t** – are, respectively, current (working) and equilibrium values of air temperature under hygrothermal conditioning,°C; *f,F* - is curvilinear trapezoid area in units of the selected scale (figure

6*A*);
m_1, m_2, M_1, M_2 – is the scale of values to be plotted along abscissa axis and ordinate axis; P, P^* – are, respectively, current (working) and equilibrium values of partial pressure in the air humidification mode, *kPa* (figure 6*B*)
4. Determine the kinetic coefficients of heat-mass transfer on the basis of thermal and diffusion similarity criteria.

The heat-transfer coefficient is determined from the below formula:

$$\alpha = \mathrm{Nu}\frac{\lambda}{l}; \tag{8}$$

The mass transfer coefficient is calculated from the below equation:

$$\beta = \mathrm{Nu}'\frac{D}{l}; \tag{9}$$

here Nu, Nu^I – are, respectively, Nusselt numbers for heating process and diffusion process. These are determined by criteria equation (see the table) [1], [8] – [10]; λ – is air thermal conductivity, W/(m·°C); l – is determinant geometrical dimension, m; D – is diffusion coefficient of water vapor in air, m^2/sec.

5. Determine the required surface of heat-exchange F^t and mass-exchange F^p in the contact apparatus for air humidification in accordance with the initial data (item 1):

$$F^t = \frac{n_t \cdot G}{\alpha}; \tag{10}$$

$$F^p = \frac{n_P \cdot G}{\beta}; \tag{11}$$

Table. Criteria equations for calculating heat-mass exchange in the process of water evaporation from body surfaces into air flow

Serial number	Author, year of publication	Criteria equation form
1	Yu.Krisher	$\mathrm{Nu} = 0{,}8 \cdot \mathrm{Re}^{0,5}$
2	D.Vyrubov, 1969	$\mathrm{Nu} = 2 + 0{,}03 \cdot \mathrm{Re}^{0,54}$
3	A.Sokolsky, F.Timofeyeva	$\mathrm{Nu} = 2 + 0{,}16 \cdot \mathrm{Re}^{0,67}$
4	Polhausen	$\mathrm{Nu} = 0{,}664 \cdot \mathrm{Re}^{0,5} \cdot \mathrm{Pr}^{0.33}$
5	E.Jillyland, T.Sherwood, 1934; with correction by K.Bennett, 1966	$\mathrm{Nu}^I = 0{,}023 \cdot \mathrm{Re}^{0,8} \cdot (\mathrm{Pr}^I)^{0,33}$
6	S.Ilyina, 2009	$\mathrm{Nu} = C^I \cdot \mathrm{Re}^{0,5} \cdot \mathrm{Pr}^{0,44}$
7	N.Fresling,1938; R.Dreik, 1961	$\mathrm{Nu} = 2 + 0{,}45 \cdot \mathrm{Re}^{0,5} \cdot \mathrm{Pr}^{0,33}$
8	B.Katsnelson, F.Timofeyeva,1948	$\mathrm{Nu} = 2 + 0{,}03 \cdot \mathrm{Re}^{0,54} \cdot \mathrm{Pr}^{0,33} + 0{,}35 \cdot \mathrm{Re}^{0,8} \cdot \mathrm{Pr}^{0,356}$
9	S.Kutateladze, 1957	$\mathrm{Nu} = 2 + 0{,}03 \cdot \mathrm{Re}^{0,54} \cdot \mathrm{Pr}^{0,33} + 0{,}35 \cdot \mathrm{Re}^{0,58} \cdot \mathrm{Pr}^{0,56}$
10	V.Isachenko et al., 1961	$\mathrm{Nu} = 4{,}55 \cdot 10^{-3} \cdot \mathrm{Re}^{0,8} \cdot K^{0,4}$
11	A.Fokin, V.Mushtayev, 1969	$\mathrm{Nu} = A + B \cdot (\mathrm{Re} \cdot \mathrm{Pr}^{0,33})$

12	A.Nesterenko, 1954	$\mathrm{Nu} = 2 + 1{,}05 \cdot \mathrm{Re}^{0,5} \cdot \mathrm{Pr}^{0,33} \cdot Gu^{0,175}$ $\mathrm{Nu}^{\mathrm{I}} = 2 + 0{,}85 Re^{0,52} (Pr^{\mathrm{I}})^{0,33} Gu^{0,135}$

3. Findings.

To humidify air in air-conditioning systems, contact apparatuses have been designed. These are notable for low consumption of power and materials. Modern technique has been proposed to calculate contact apparatuses. The technique makes it possible to determine the required heat-mass transfer surface under adiabatic humidification of air.

References

[1] Averkin A G and Eremkin A I 2015 *Improvement of Devices for Heat and Humidity Treatment of Air and Methods for Calculating Climate Equipment* (Penza: PGUAS) p 204
[2] Lewis W K 1933 ASME Vol 55 **9** 567-8
[3] Bogoslovsky V N and Gvozdkov A N Proceeding HB'94 Budapest Vol **1** 381-4
[4] Merkel F 1925 *Evaporation Cooling. Research Work, From the Field of Engineer* (Being Issue **275** V D I) p 48
[5] Ramachandran S et al 2016 *Thermal Engineering* II (Airwalk Publications) p 766
[6] Rash R 1970 *Theory and practice of Luftwashers in the technique of aeration* Air conditioning B 12 **9** pp 12-31
[7] Averkin A G and Kiselev S O 2017 *Slovenia Journal of scientific thought* Vol 1 **7** 80-3
[8] Hong S W 1974 *Laminar Flow Heat Transfer in Ordinary and Augmented Tubes* (Ames: Iowa State University) p 291
[9] Wibulswas P 1966 *Laminar-Flow Heat-Transfer in Non-Circular Ducts* (London: University College London) p 150
[10] Raju K S N 2016 *Fluid Mechanics, Heat Transfer, and Mass Transfer* (Chemical Engineering Practice Published by John Wiley Sons Inc Hoboken New Jersey) p 736