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ENERGY-EFFICIENT COMBINED SHOCK-FOAM-TYPE AIR-HANDLING UNIT WITH BLOCK OF THERMOELECTRIC MODULES FOR AIR CONDITIONING SYSTEMS

The paper deals with the heat and mass transfer process research and calculation of the combined shock-foam-type air-handling unit with block of thermoelectric modules that create microclimate parameters during the museum pieces transportation and it storage in special premises. The air conditions variation range in air-handling unit is not limited to contact heating device, by combination of surface and contact heat exchangers in one construction, as well as turbulence in gas-liquid system provides intensification of the heat and mass transfer processes and air purification from impurities. However, combined shock-foam-type air-handling unit is compact, lightweight, energy efficient and make possible a temperature and cooling capacity variable control.

Keywords: **shock-foam-type air-handling unit, mass aerodynamic drag, the number of transfer units, head of foam, static fluid level, coefficient of heat transmission**

INTRODUCTION

Formation of the collections and exhibit storage are the main museum activities and they determine a composition and structure arrangement of building, and provide a special scientifically based air quality maintenance plane. Creating optimal microclimate parameters in the museum premises is a complex task. On the one hand it is a creation of such conditions that would ensure long term of museum specimen preservation, based on the characteristics of each material, on the other hand creating a comfort conditions for people, visitors and employees of the museum.

Nowadays, the optimal parameters of the microclimate in the museum premises created using central or self-contained air conditioning systems with air handling and air-conditioning equipment. Today there is much tension around the issue of creating and maintenance microclimate parameters during transportation and it storage in premises of disinfection, disinsectization, acclimatization, insulators, scientific and research laboratories. These premises characterized by small volume, with complex planning and have it is own, specific requirements for microclimate parameters. In each of these areas their own, specific requirements for microclimate parameters, based on the characteristics of museum specimen material. Different museum specimen has their own requirements of temperature and relative humidity and they are changing in wide range [1].

In addition to well-known harmful influence of temperature and relative humidity difference, the gas composition of the air has a great influence on museum specimen. In the museum, there are wide ranges of internal sources of pollution, except of external sources. The main impurities are microscopic gaseous particles, sulfur dioxide, nitrogen oxide and ozone oxide, dust, aerosols, fog of different origin and other [1].

Such premises demand instrumentation of self-contained air conditioning units, to perform the air-handling process under each of the specific areas.

We investigate a possibility of complex approach of indoor air condition maintenance and providing air purification in a parallel with temperature and humidifying conditions. The aim of the research was to create a compact, lightweight, energy efficient and independent of spatial location, self-contained air-handling unite that could maintain optimal microclimate parameters over a wide range and ensures efficient air purification from various types of pollutions and make possible a temperature and cooling capacity variable control.

1. ANALIZE OF LAST RESEARCH

The most intensive open-type heat exchangers are devices were air-conditioning and purification take place in foam layer. Foam method water dispersion except need in nozzles that conduce reliability growth of working conditions [2].

A number of researchers has studied processes of hydrodynamics, heat and mass transfer in foam layer [3-7]. All authors have noted the fact that with putting heat exchanger in turbulent foam layer the coefficient of heat transfer from liquid to heat exchanger surface increase significantly. Research works showed that hydrodynamic conditions have overwhelming influence on the heat transfer in foam layer. In most of these works were studied heat exchanger with intermediate heat-transfer agent. In present work, we use heat-sink heat exchangers, as they have good weight characteristic, are compact and do not need mechanical refrigerating compressor unit [3].

However, due to the strong influence of combined shock-foam-type air-handling unit features on subject to conditions heat and mass exchange, we cannot obtain adequate definition of thermotechnical calculation for new construction. Therefore, the research task was to analyze foam layer hydrodynamics, heat transfer to heat exchanger surface and heat exchange between water and airflow [5].

2. AIR-HANDLING UNIT DESIGN AND PRINCIPLE OF OPERATION

By analyze handling units their advantages and disadvantages we have developed and patented a new combined shock-foam-type air-handling unit with a block of thermoelectric modules (Fig. 1). The handling belong to surface trickling heat exchangers, which combine a contact and surface heat exchangers in one design [8, 9].

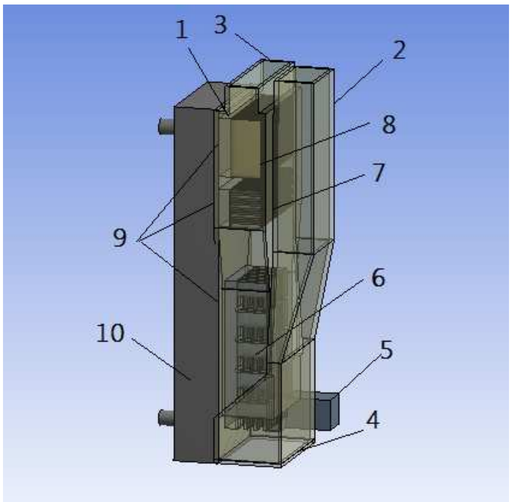

Fig. 1. Combined shock-foam-type air-handling unit with a block of thermoelectric modules design: 1 - air-conditioner cabinet; 2 - inlet opening; 3 - out let opening; 4 - water-collecting sump; 5 - water-level controller; 6 - heat exchange with foam stabilizer function; 7 - heat exchange with drift eliminator function; 8 - heat exchange; 9 - thermoelectric modules; 10 - circulating circuit

Handling unit woks in the following way. An air blow on the water surface through inlet opening 2. Water fill out water-collecting sump 4, with water level regulator 5. Airflow pressure effect on water surface bring to displacement some of the liquid from water-collecting sump 4. Displacement liquid rapidly mixed with air, therefore, formed a moving foam layer, that flow over heat exchange 6 with foam stabilizer function. In top part of air-handling unit appear water drops that entrained by airflow from foam layer. Air with water drops flows over the fins of heat exchanger 7, which fulfil a function of drift eliminator. The air flows through heat exchanger surface 8. Conditioning air removed through outlet 3.

Top part of air-handling unit made with smooth widening in relation to reactive space. This feature reduce airflow velocity and kinetic energy of water drops that entrained from foam layer. In addition, it allows increasing heat exchanger surface and term of heat transfer processes.

The processes that take place in handling unit depend on temperature of heat exchangers. As a heat and cold source for heat exchangers, thermoelectric modules 9 are used. Their work based on the physical effect Paltye. For effective heat or cold remove of thermoelectric modules air-handling unit, complete with auxiliary channel 10. In channel liquid or gas are circulated. In parallel with purification handling unit provide cooling, heating, adiabatic humidifying, cooling with humidifying, cooling with dehumidifying processes.

Strong turbulence of gas-liquid system provides a heavy increase of contact surface interacting phases. It lead to intensification heat transfer from water in foam layer to surface and heat-mass-exchange between air and water.

The possibility of transferring the thermoelectric modules from cooling to heating regime provides an opportunity to spread air conditioning range. The small size and weight of thermoelectric modules extend their field of use.

3. EXPERIMENTAL RESULT AND DISCUSSION

The processes in combined shock-foam-type air-handling unit present a hard problem for description because of the complex phenomena of heat and mass transfer in turbulent foam layer.

We realize experimental study to analyze the air-water behavior and heat transfer between surface of heat exchangers and foam layer and it dependence from design and hydrodynamics features of a shock-foam-type air-handling unit.

The pressure drops and heat transfer efficiency in shock-foam-type air-handling unit depend on hydrodynamics features between water and airflow in air-handling unit. As we can see on Figure 2, hydrodynamic factors include static water level and air velocity in the cross section of the air-handling unit.

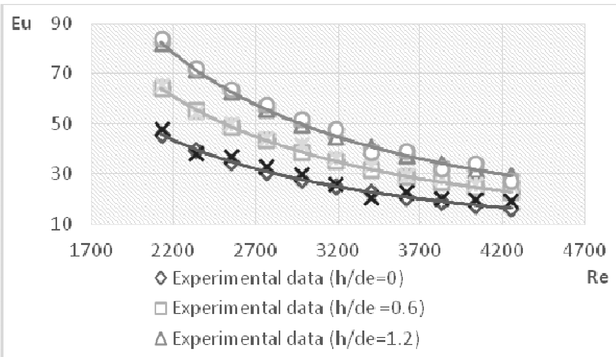

Fig. 2. Euler number as a function of air Reynolds number and static water level evaluated from experimental results for heat exchanger which is placed in underpart of air-handling unit

Heat transfer coefficient of heat exchanger placed in foam layer depend on static water level, air velocity in the cross section of the air-handling unit and physical water properties. The main influence on heat transfer efficiency has static water level, as with it increase height of foam layer increase too. Less influenced have air velocity and the density of the liquid (Fig. 3).

Analysis of experimental data shows that the foam layer was the main factors that influence on the heat and mass transfer efficiency and pressure drops in air-handling unit (Fig. 2). To evaluate the heat and mass transfer intensity between air and water in foam layer we use the number of transfer units.

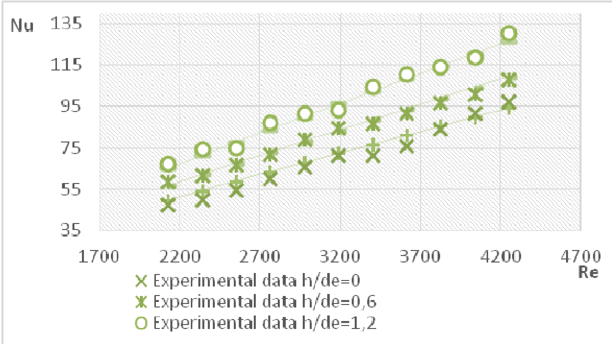

Fig. 3. Nusselt number as a function of air Reynolds number evaluated from experimental results of heat exchanger which is placed in underpart of air-handling unit

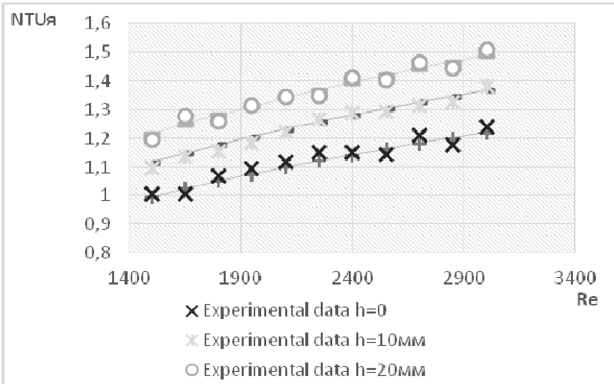

Fig. 4. Number of transfer units as a function of air Reynolds number and static water level, evaluated from experimental results of air-handling unit

Analyzing Figures 2 and 4 we allow that increase in air velocity and standing-water level significantly increase the intensity of heat mass transfer, and therefore the overall unit capacity, but it increases the pressure loss of the unit.

Since the intensity of heat transfer and energy costs are a function of the same variables, it is possible to adjust the cooling capacity of the unit cost.

4. APPROXIMATE EQUATIONS

Shock-foam-type air-handling unit combine open-type and surface heat exchanger in one design. Process that take place in air-handling unit divide on two steps, first step heat transfer from water to heat exchanger surface and second step heat exchange between water and air in foam layer. To make thermotechnical calculation of air-handling unit it is necessary to dispose characteristics for each step.

Research result of heat transfer from water in foam layer to heat exchanger surface placed in foam layer and for heat exchanger placed at the top of air-handling unit contact only with airflow, generalized dependences:

$$Nu_1 = 0.045\, Re_g^{0.92+0.01h/de}\, Pr_L^{0.015} \quad (1)$$

$$Nu_2 = 0.01 Re_g^{2.05}\, Pr_g^{0.4} \quad (2)$$

were: $h_{ст}$ - static water level [m]; Nu - Nusselt number

$$Nu = \frac{\alpha_s \cdot d_e}{\lambda_L} \quad (3)$$

λ_L - water heat conduction coefficient [W/(m·K)]; d_e - equivalent diameter, which was adopted by an analog hydraulic mean depth [m]

$$d_e = \frac{4V}{F} \quad (4)$$

were: V - volume between heat exchanger fins [m^3]; F - wetted surface area [m^2].
Re_g - Reynolds number

$$Re_g = \frac{w_g d_e}{\nu_g} \quad (1)$$

Pr_L - Prandtl number for water flow

$$Pr_L = \frac{\nu_L}{\alpha_L} \quad (2)$$

ν_L - water kinematic viscosity coefficient [m^2/s]; α_L - temperature conductivity coefficient of liquid [m^2/s].

The number of transfer units, takes the following general form:

$$NTU_я = \frac{\alpha F_R}{c_g G_g} = \frac{t_1 - t_L}{t_2 - t_L} \quad (7)$$

$$NTU_я = \frac{\sigma F_R}{G_g} = \frac{I_1 - I_L}{I_2 - I_L} \quad (8)$$

were: α - heat-transfer coefficient [kJ/(m^2·h·K)]; F - heat -exchange surface [m^2]; t_1, t_2 - inlet and outlet air temperature [K]; σ - mass-transfer coefficient [kg/m^2·h]; I_1, I_2 - inlet and outlet air enthalpy [kJ/kg]; t_L - water temperature in foam layer [K]; I_L - air enthalpy equilibrium with water temperature in foam layer [kJ/kg].

Dependence number of transfer units from determine parameters present on the Figure 4 and generalized by equations:

$$NTU_я = 0.015 G^{0.3}\, Re_g^{(0.42+0.028G)}\, Pr^{0.15}\, T^{0.064} \quad (9)$$

$$NTU = 0.027 G^{0.22}\, Re_g^{(0.36+0.01G)}\, Pr^{0.15} \quad (10)$$

were T_0 - temperature factor:

$$T_0 = \frac{t_1 - t_{dt}}{t_1 - t_L} \tag{3}$$

were t_{dt} - dewpoint temperature [K];
G - geometric simplex:

$$G = \frac{H}{d_e} \tag{4}$$

were H - foam level [m];

$$H = \frac{\Delta P}{g \rho_L} \tag{5}$$

ΔP - foam layer aerodynamic drag [Pa]; ρ_L - water density [kg/m^3]; g - acceleration of gravity [m/s^2].

Foam layer aerodynamic drag calculate by dependence Euler number from determine parameters:

$$Eu = \left(5.2 + 0.29 \frac{h_{st}}{d_e} \right) \cdot 10^3 \, Re^{-1.49} \tag{6}$$

were Eu - Euler number:

$$Eu = \frac{\Delta P}{\rho_g w_g^2} \tag{7}$$

ΔP aerodynamic drag [Pa]; w_g - air velocity in cross-section of air-handling unit [m/s]; ρ_g - air density [kg/m^3].

CONCLUSIONS

Experimental data allowed analyzing air-water behavior and heat transfer between heat exchangers surface and foam layer and it dependence from design and hydrodynamics features of a shock-foam-type air-handling unit.

Were detected that processes which take place in the working space of air-handling unit were the most intensive when the static water level were 20 mm and air velocity in the cross section of the air-handling unit were 3 m/s.

The intensification of heat and mass transfer processes and efficiency of heat transfer achieved by combination of heat exchange and foam stabilizer in a single design. The design of the heat exchanger reduce resistance heat flow from the heat exchange surface to water prevent foam layer oscillations at high air velocity.

Processes of heat and mass transfer in combined shock-foam-type air-handling unit is in 30÷45% effective then in spray chamber. Heat transfer coefficient from water in foam layer to heat exchange surface with foam stabilizer function come up to 3000÷4500 $W/m^2 \cdot K$, that is in 20% higher then heat exchange with intermediate heat-transfer agent in the form of tube bundle.

Energy efficiency and competitive ability of combined shock-foam-type air-handling unit achieved by reducing the dimensions and weight of air-handling unit, increasing environmental safety, intensification of heat and mass and heat transfer in the foam layer, the possibility of a wide range of air condition processes from cooling-dehumidifying to heating-humidifying, including adiabatic humidification.

REFERENCES

[1] Technical standards, Recommendations for the designing of museums, Stroyizdat, M.: 1988.

[2] Bogatuh S.A., Complex air handling in foaming apparatus, Bogatuh S.A., Sudostroenye, L.: 1974, 316 s.

[3] Stefanov E.V., Research of modernized scheme spray chamber. Air conditioning in the industrial public and residential buildings, Stefanov E.V., Korkin V.D., Stroyizdat, M.: 1965.

[4] Barskiy M.A., Kuplenov N.I., Heat and mass transfer in the absorption unit, Refrigerating Engineering 1976, № 3, c. 33-37.

[5] Kuplenov N.I., Investigation of the processes of heat and humidity of air treatment with a solution of lithium chloride and water in the foam heat exchange unit, LVVISKU, L.: 1976.

[6] Merchanskiy V.D., Bahenskiy V.A., On the outer heat transfer in foam-evaporative air cooler, Refrigerating Engineering 1986, № 3, c. 38-41.17.

[7] Merchanskiy V.D., Investigation of Heat and Mass in the foam unit for refrigeration and air conditioning, Refrigerating Engineering 1983, № 5, c. 26-31.

[8] Pat. №101290 Ukraine IPC F24F 3/ Thermal and humidity air-handling unit, Dovgalyuk V.B., Shadura I.V. appl. 12.06.12, post. 11.03.13, Gaz. № 5/2013.

[9] Pat. № 106579 Ukraine IPC F24F 3/ Air-handling unit/ Dovgalyuk V.B., Chaban I.V. appl. 26.12.13, post. 10.09.2014, Gaz. № 17/2014.

ENERGOOSZCZĘDNE URZĄDZENIE UDAROWO-PIANNE Z BLOKIEM MODUŁÓW TERMOELEKTRYCZNYCH DLA SYSTEMÓW KLIMATYZACYJNYCH

Wyniki badań i obliczenia połączonego urządzenia udarowo-piannego z modułami termoelektrycznymi, zapewniającego optymalne parametry środowiska powietrznego zarówno jak podczas przemieszczenia obiektów muzealnych jak i podczas ich przechowywania w specjalnych pomieszczeniach. Dzięki kombinacji powierzchniowych i kontaktowych wymienników ciepła w jednej konstrukcji zakres zmiany parametrów powietrza nie jest ograniczony do funkcji urządzeń kontaktowych, ponadto turbulizacja przepływu gazu i płynu zapewnia intensyfikację procesów ogrzewania i oczyszczenie powietrza od zanieczyszczeń. Dodatkowo kombinowane urządzenie udarowo-pianne jest kompaktowe, lekkie, energooszczędne o pławnej regulacji temperatury i mocy chłodniczej

Słowa kluczowe: **urządzenie udarowo-pianne, opór aerodynamiczny, liczba jednostek transferu, warstwa pianki, statyczny poziom płynu, współczynnik przenikania ciepła**