Developing a new method of calculating heat and humidity air treatment by water in irrigation chamber

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Abstract. The air treatment processes in the air conditioning systems are the main part of air conditioning. This paper presents the new corrected method of heat and humidity treatment calculation of air by water, where not only the heat transfer process between water and air is taking into account but also the mass transfer process. The accuracy of the suggested method verified using the calculations to determine the parameters of air and water in various real processes of heat and humidity air treatment, shown in the psychometrics chart of various scales. Application of the suggested method gives an opportunity to find out the correct technical solutions and the required processes of heat and humidity air treatment in the irrigation chambers of air conditioning units. Based on the calculations using the new method gets that the irrigated water must cool up to 30% deeper than the calculation with the existing method.

1 Introduction

Heat and humidity treatment of air with water is widely used in air conditioning technology [1-8]. These processes of heat and humidity treatment of air usually take place in the irrigation chambers of the air conditioning units, in which the water is sprayed into the treated air and irrigate it [9]. In the irrigation chamber, the air condition changing upon contact with the water, takes place due to sensible Qsens and latent Qlat heat exchange [10]. The air condition changing process characteristic depends on the initial temperature of the water and the amount of water sprayed to treat 1 kg of air. To calculate these processes and, accordingly, the irrigation chambers, the following formula for determining the final and initial temperatures of water obtained based on the balance of heat flow between air and water is currently widely used [5].

$$\left(t_{w2} - t_{w1}\right) = \frac{\left(h_{air1} - h_{air2}\right)}{c_w \mu} \tag{1}$$

where: t_{w1}, t_{w2} are the initial and final temperature of water in the irrigated chamber, ^oC
c_w is specific air heat, kJ/(kg ^oC)

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hair1, hair2 define initial and final enthalpy of treat air, kJ/kg

μ is a coefficient of irrigation.

The last formula is obtained based on the energy balance between air and water, during which the air gives the sensible heat to the irrigated water.

$$Q_{sens} = G\left(h_{air1} - h_{air2}\right) \tag{2}$$

where: G is a quantity of treat air, kg/s

It should be noted that the formula (1) is very simplified, does not represent the real view of the air and water changing processes, and apart from that does not provide the accuracy of calculations for air treat processes. This conclusion is proved based on the fact that during the contact of air with water, in reality, between them take place not only the heat transfer processes described by the formula (2) but also the mass transfer processes due to the water evaporation absorbed air. The process can be conditionally divided into two main parts:

1. transferring the sensible heat by air to water, as a result of which the enthalpy of air changes from the initial value to some intermediate value.
2. evaporation of water and absorption of vapors by the air, due to which the air is humidified.

As we can see, in the well-known method of calculation, the environment in the chamber is biphasic, so it consists only of a mixture of water and air, the masses of which unchanged during the process. However, in reality, between air and water take the heat and mass transfer process in the result's vapor transfer from air to water and in the opposite direction, and in this case, change the mass of water and air. This phenomenon eventually affects the final parameters of "air" and "water", as well as the quantitative characteristics of heat and mass transfer. To develop an accurate method for calculating the irrigation chamber, the above factor was taken into account, assuming that the environment of the irrigation chamber is a three-phase system consisting of sprayed droplets of water, air and water vapor.

2 The irrigation water initial temperature calculation and determination method

According to the above-mentioned approach, we suggest calculating heat and mass balance in the irrigation chamber, taking into account the following conditions:

1. the availability of both sensible and latent heat transfer between air and water in the irrigation chamber,
2. change the water mass and moisture content in air during heat transfer,
3. influence of the water initial temperature and the irrigation coefficient on the process of changing air condition.

For understanding the real mechanism of heat transfer, let's assume that the initial amount of air is equal to G_{air}, and water is W. The amount of superheated vapor G_{vp} emitted from the water absorbed by the air will be:

$$G_{vp} = G_{air}\left(d_{air1} - d_{air2}\right) \quad \text{or} \quad G_{vp} = G_{air}\Delta d \tag{3}$$

where: d_{air1}, d_{air2} –initial and final humidity ratio of air, gr/kg

As a result of the vapor exchange, the quantity of air G_{air2} will increase:

$$G_{air2} = G_{air} + G_{vp} \quad \text{or} \quad G_{air2} = G_{air} + G_{air}\left(d_{air1} - d_{air2}\right) \quad \text{or} \quad G_{air2} = G_{air}\left(1 + \Delta d\right) \tag{4}$$

For the same reason, the amount of water W will decrease:

$$W_2 = W - G_{vp} \quad \text{or} \quad W_2 = W - G_{air}\left(d_{air1} - d_{air2}\right) \quad \text{or} \quad W_2 = W - G_{air}\Delta d \tag{5}$$

Taking into account the new, more detailed description of the air-water heat and mass transfer process, the air-water heat balance will be expressed by the following equation:

$$G_{air}h_{air1} - Q_{sens} + Q_{lat} = G_{air2}h_{air2} \tag{6}$$

where: Q_{lat}, Q_{sens} –sensible and latent quantity of heat, kW.

The latent heat given by the water vapor to the air can be estimated by the following expression:

$$Q_{sens} = G_{air}\left(d_{air1} - d_{air2}\right) r \text{ or } Q_{sens} = G_{air}\Delta d\ r \tag{7}$$

where: r -latent heat of water vapor, which is taken equal to 2487 kJ/kg [10 -12].

Substitution of formulas (7) and (4) into equation (6) after simplifications, the amount of sensible heat transferred from air to water is determined by the following expression:

$$Q_{sens} = G_{air}\left(h_{air1} - h_{air2}\right) + G_{air}\Delta d\left(r - h_{air2}\right) \tag{8}$$

Getting the quantity of heat Q_{sens} from the air, the quantity water W_2 is heated from the initial t_{w1} to the final t_{w2} temperature. Using the balanced equation $Wc_wt_{w1}+Q_{sens}=W_2c_wt_{w2}$ and putting formulas (5) and (3) into it, making some simplification will be determined the following equation:

$$Q_{sens} = Wc_w\left(t_{w2} - t_{w1}\right) - G_{air}\Delta d c_w t_{w2} \tag{9}$$

Equating (8) to (9) and making some simplifications the following new equation is obtained, using which can determine a more exact value of the initial required temperature of the water sprayed in the water chamber:

$$t_{w1} = t_{w2} - \frac{\left(h_{air1} - h_{air2}\right)}{\mu c_w} + \frac{\Delta d\left(r - h_{air2} + c_w t_{w2}\right)}{\mu c_w} \tag{10}$$

The obtained equation (10) is universal and can be used for all processes for heat and humidity treatment of air. Based on the universal equation, the calculation formulas can be obtained to accurately determine the air-water parameters in various processes of mutual interaction.

The comparison of the obtained equation with the known expression shows that the (1) is only part of the equation (10) because the new method takes into account many factors, particularly changing the mass of air and water during the process.

3 Analysis of the proposed calculation method

The analysis of the suggested method also proves the fallacy of the existing position that in the so-called processes of isenthalpic cooling or adiabatic humidification, for which ε=0 (or $h_1 = h_2$) and $\Delta d = d_{air1} - d_{air2} < 0$, the water temperature stayed constant, or the temperature difference of water in irrigation chamber is equal to zero. That is, to provide an ideal adiabatic process, the temperature of the sprayed water must be lower than the final water temperature on the value (11).

$$\Delta t_w = \frac{\Delta d\left(r - h_{air2} + c_w t_{w2}\right)}{\mu c_w} \qquad (11)$$

To identify the values of change the water temperature in the adiabatic humidification processes were made the calculations by using a psychometric chart [13]. Based on the charts and assuming the value μ=0.7 [14] were determined; the values of Δt_w depend on Δd. The results of calculations are shown in Fig.1.

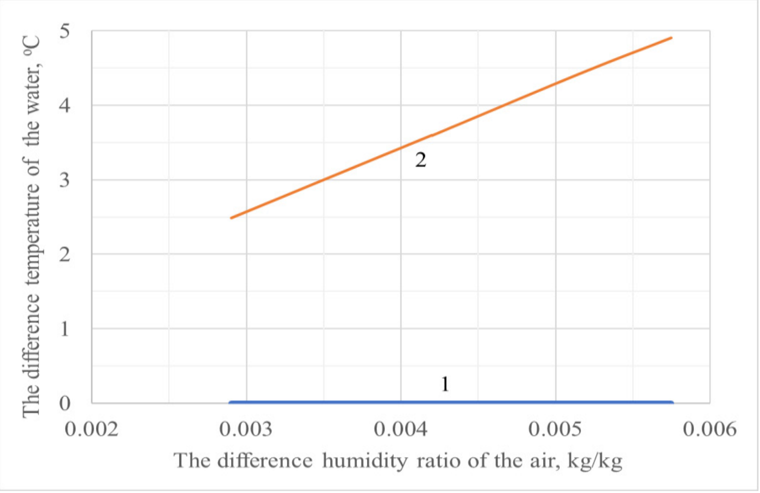

Fig. 1. The graph dependence of water temperature difference on the difference humidity air ratio at the Δh=0 (ε =0). 1- the existing method, 2 – the suggested method

The graphs show that in adiabatic processes the water temperature changes in proportional to the changing of humidity ratio. It should be noted that this phenomenon is also observed in real installations of adiabatic air humidification. Laboratory tests and measurements also prove the variability of water temperature in wet-type air coolers.

Another proofing of checking the correctness of the proposed method is that the existing formula for determining Δt_w is a special case of the proposed more universal calculation method, in particular for the so-called dry heating or cooling processes occurring at a constant humidity ratio *d=const*, or Δd=0. From the suggested equation following that for processes with Δd=0, the value of Δt_w is the same both for the suggested and for the existing method, that is to say, with Δd=0, the proposed expression (10) takes the form of (1). For additional proving the correctness of the suggested method, the calculation was made for determining Δt_w, for processes with Δd=0 at various values of Δh. The calculation results are shown in Fig. 2.

As follows from the graphs, for any values of Δh, the values of Δt_w, the calculations by the existing and suggested equations, are quite the same. This is proof of the suggested method correctness. However, with an increase in the value of Δh, the values of Δt_w also increase. The correctness of this conclusion is proved by the fact that for $\varepsilon \to \infty$ processes with (dry heating or cooling), in which there is no evaporation of water, due to the lack of contact between air and water, the values of the water temperature difference Δt_w, both on the proposed and the existing methods converge. This also means that the suggested method is more universal, and the existing method is its special case.

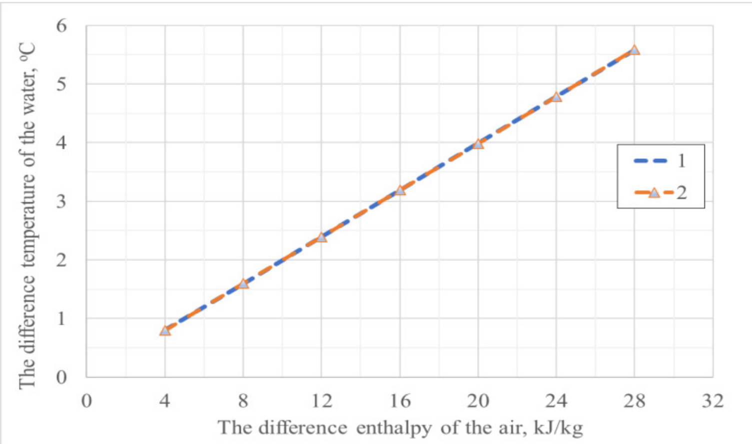

Fig. 2. The graph dependence of water difference temperature on the difference air enthalpy at Δt=0 ($\varepsilon = \infty$). 1- the existing method, 2 - the suggested method

The stated provisions and conclusions were also verified using a psychometric chart with different scales. Fig. 3 shows the graphs of water temperatures difference determined by the existing and suggested methods using a psychrometric chart with different scales of (685mmHg, 700 mmHg, 760 mmHg).

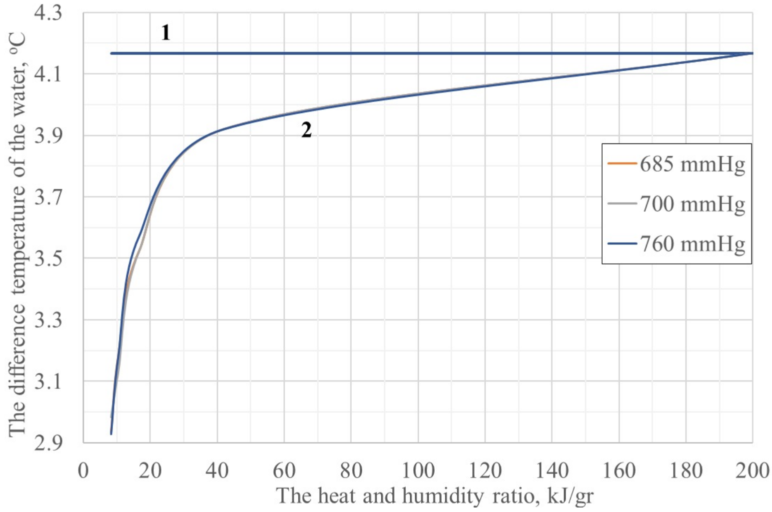

Fig. 3. The graph dependence of water difference temperature on heat and humidity ratio for atmospheric pressures 685mmHg, 700mmHg, 760mmHg. 1- the existing method, 2 – the suggested method

As it can be seen from the graphs, the water temperature differences Δt_w are the same for all scales of the psychrometric charts at different values of ε processes. It is also interesting to study the suggested method for processes in which the enthalpies change randomly, that is, the values of Δh taking any values due to the character of the processes of heat and humidity treatment of air (values ε). Based on the graph is clear using the new method gets that the irrigated water must cool up to 30% deeper than the calculation with the existing method.

5 Conclusion

To make a real adiabatic process and provide constant air enthalpy, the sprayed water must be pre-cooled.

To make a real dehumidification polytropical process, the sprayed water must be pre-cooled.

To make a real humidification polytropical process, the sprayed water must be pre-heated or pre-cooled.

Existing irrigation chambers with the direct circulation of water are not suitable for the adiabatic process, as they must have a system to pre-cool the irrigated water.

The irrigation chamber should be equipped with both a cooling system for pre-cooling the water and a heating system for pre-heating the water.

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References

1. B. Whitman, B. Johnson, J. Tomczyk, E. Silberstein, *Refrigeration & Air Conditioning Technology* 25th Anniversary 7th Edition, Cengage Learning (2012) ISBN: 978-1111644475
2. D.S. Filimonov, A.A. Makarov, Fibre Chem **43**, 181 (2011), DOI doi.org/10.1007/s10692-011-9331-2
3. E. S. Bondar, A. S. Gordienko, et al., Modern Ventilation and Air Conditioning Systems: A Textbook [in Russian] (Vidavnichii Budinok “Avanpost-Prim,” Kiev, 2005)
4. F. Kreith, K. Shan Wang, P. Norton, Air Conditioning and Refrigeration Engineering (CRC Press, 2019) ISBN 9780367399177
5. G. A. Maksimov, Air Conditioning Processes’ Design (Book on Demand Ltd, 2013)
6. G. F. Hundy, A.R. Trott, T.C. Welch, Refrigeration, Air Conditioning and Heat Pumps 5th Edition (Butterworth-Heinemann, 2016) ISBN 9780081006474
7. T.N. Il'ina Air conditioning and cooling (Profobrazovanie, Saratov, 2020) ISBN 978-5-4488-0562-2
8. V.M. Svistunov Heating, ventilation and air conditioning at the agro-industrial complexes and urban housing (Politehnika, Sankt-Peterburg, 2020) ISBN 978-5-7325-1088-1

9. M. J. Sánchez-Blanco, T. Ferrández, A. Navarro, S. Bañon, J. J. Alarcón, Journal of Plant Physiology **161**, 10, 1133-1142 (2004) DOI doi.org/10.1016/j.jplph.2004.01.011
10. Z. A. Melikyan, Heating–Cooling of Buildings. Efficiency of Conventional and Renewable Technologies (LAP Lambert Academic Publishing, Germany, 2012) SBN: 978-3-8443-1939-2.
11. T. L. Bergman, A.S. Lavine, F.P. Incropera, D.P. DeWitt, Fundamentals of Heat and Mass Transfer (7th Edition Binder Ready Version Wiley, John Wiley & Son, 2011) ISBN-13: 978-0470917855
12. H. Baehr, K. Stephan, Heat and Mass Transfer, Third revised edition (Springer-Verlag Berlin Heidelberg, Berlin, 2011) ISBN 978-3-642-20020-5.
13. ASHRAE handbook. 2017 Fundamentals, Chapter 1 Psychrometrics (Atlanta, Ga., 2017)
14. A.M. Whitman, Thermodynamics: Basic Principles and Engineering Applications 1st Edition (Spring, 2019) ISBN: 978-3030252205