UDC 66.045.54

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Calculation of performance of ventilatory cooling towers

Abstract. This article provides aerodynamic and thermal calculation of ventilatory cooling towers depending on atmospheric conditions (temperature, humidity, pressure) of an area. The features of modern water circulation systems of cooling the equipment via ventilatory coolers are considered. The factors that influence the stability, reliability and efficiency of the cooling towers are analyzed. The formulas for determining the properties of moist air are presented, and methods of engineering calculations of a ventilatory cooling tower based on the experimental data in the field of parameters of atmospheric calculations for aerodynamic and climatic conditions are presented. Based on thesecalculations the software complex with the usable interface developed.
Key words: cooling tower, calculated dependencies, relative humidity, water catchers.

Introduction

The ventilatory cooling tower is the device intended for dispersion in atmospheric air of a flow of heat received by the cooling water in cooling devices. In the cooling tower there is a direct contact of the cooled water with atmospheric air.

Warm water gets to the main collector of a water distributor. Further there is transport through system of pipes to nozzles. Nozzles spray water streams on a sprinkler, creating the water screen with the big surface of contact. The water which is coming off bottom edges of elements of a drain of a sprinkler falls down in the form of a rain in the pallet which is under the cooling tower from where it is forced back in the cooling device.

Process of chilling of water takes place, in the main measure, due to evaporation by the proceeding current of air of a small part of a stream of the cooled water (weight transport), with use of heat of phase transition (warmth of evaporation) received from a water stream and also – in a smaller measure – due to convective heat exchange between water and air (heat transport).

The counterflow current of air in cooling towers, is caused by exhaust influence of the axial ventilator which productivity is picked up to the required cooling parameters. The fan is installed in the case, on overlapping of a compartment of the cooling tower. Air is involvedin a compartment through the entrance windows equipped with blinds which protect from hit of solid bodies from the environment, for example leaves, and also from spraying of the cooled water out of the cooling tower. Further the involved air passes through the rain zone under sprinklers, through irrigative filling, in the zone of spraying of water over a sprinkler, and further there is a capture of drops by the water catcher which minimizes loss of water due to stealing of drops. The warmed-up and watered air proceeds via the fan, then, through the top section of the cage of the fan it is blown outside to the environment.

Extent of cooling of water in the wet cooling tower depends on temperature of the thermometer of the damp air involved outside, the air volume (fan productivity) and technical solutions of the cooling tower. Cooling towers are designed for obtaining the expected effect of cooling in the most adverse conditions (high temperature and humidity of air) and taking into account need of a conclusion of the maximum quantity of heat from water.

Features of process of chilling of water in cooling towers

Chilling of water in cooling towers is performed by transfer of heat to atmospheric air due to superficial evaporation of water and hat transfer contact (heat conductivity and convection). Heat can be taken away from water and due to the radiation. However the amount of heat transferred by radiation so isn't enough that in case of creation of thermal balance of the cooling tower neglect it.

During the most part of year the prevailing role is played by superficial evaporation. In the summer during a heat about 90% and more heat, given by water are the share of evaporation. In the winter heat transfer with contact increases up to 50%, and in the coldest time up to 70%, against 10-20% and less during the summer period. "Driving force" of process of evaporation of water in the cooling tower is the difference of partial vapor pressure at a water surface and in a kernel of an air flow. In case of heat transfer contact by such driving force is the difference of water temperatures and air. In the cooling tower the atmospheric air, which is damp, is arrived as it always contains a certain amount of the vapors of water which are usually in a superheated condition. For thermal calculations of cooling towers with sufficient degree of accuracy is accepted that damp air, which can be considered as mix of dry air and water vapor, submits to laws of mix of ideal gases. Dry air and steam occupy the same amount as all mix.

The key parameters characterizing a condition of damp air are pressure, temperature, density, moisture content, relative humidity, an enthalpy.

Under Dalton's law pressure of damp air corresponding to the barometric pressure P_b is equal to the amount of partial pressure of dry air of$P_{a,d}$ and water vapor of P_v:

$$P_b = P_{a.d} + P_v \quad (1)$$

Partial pressure of water vapor in the cooling tower isn't enough compared with very slightly changing barometric pressure, therefore in further conclusions of estimated dependences it is accepted

$$P_{a.d} = P_b - P_v = Const \quad (2)$$

Partial pressure of dry air and steam are defined from Mendeleyev-Clapeyron's equation:

$$P_{a.d} / \gamma_{a.d} = R_{a.d} T \cdot 10^{-4}; \; P_v / \gamma_v = R_v T \cdot 10^{-4} \quad (3)$$

where T – temperature, K; $\gamma_{a.d}$- density of dry air, kg/m3; γ_v – density of vapors of water, kg/m3.

Density of damp air is equal to the sum of density of dry air and steam:

$$\gamma_{damp} = \gamma_{a.d} + \gamma_v = \frac{P_b - \phi P_v^{"}}{R_{a.d}(\vartheta + 273{,}2)} + \phi \gamma_v^{"} \quad (4)$$

It is useful to note that density of damp air goes down with reduction of pressure, with temperature increase and relative humidity.

Communication between key parameters of damp air for convenience of practical calculations and presentation can be presented in a graphic form. Thei-d-charts, representing graphic functional dependences of enthalpies on moisture contents with the put lines of constant values of temperatures and relative humidity, have the widest extension. For improvement of expansion of lines φ = Const the corner between axes of coordinates is accepted equal 135°. Charts are constructed for certain barometric pressure 500, 740, 1000 mm of mercuryetc. A theoretical limit of cooling of water by air is air temperature on the watered thermometer ϕ. It is reached by moistening of air without additional removal or supply of heat to saturation condition (φ = 100%), i.e. at adiabatic evaporation. Oni-d-chart value ϕ is defined by a point of intersection line i = Const passing through the point characterizing a condition of damp air with the line φ = 100%.Consequently by value ϕ unambiguously it is possible to determine values of an enthalpy and moisture content of air.

Calculation of ventilatory cooling tower

The cooling tower represents the heatexchange device in which the heat carrier – water transfers warmly to coolant – air by direct contact. For ensuring necessary surface area of contact the cooling tower is equipped with a special element – the irrigating device (sprinkler). The significant contribution to development of methods of calculation of cooling towers is made by F. Merkel, B. V. Proskuryakov, L. D. Berman, I. Liechtenstein and other authors. L. D. Berman's monograph till today is the reference book of the engineering employees who are engaged in designing, operation and a research of cooling agents of turnover water. The widest extension and general recognition in the world gained Merkel's method. The detailed statement and discussion of a method of Merkel is published in a number of books and numerous articles. The modern option of a conclusion of the equations describing process of a heat mass exchange in counterflow cooling towers, in relation to practical calculations of these constructions taking into account the assumptions accepted by Merkel, is given in this handbook in summary form.

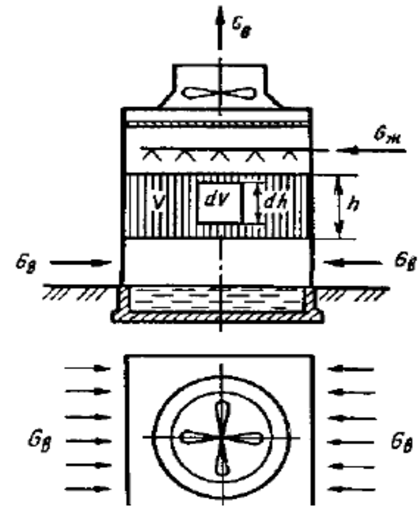

Figure 1 – Scheme of the ventilator cooling tower

In the Figure1 the scheme of the ventilator cooling tower is shown. The balance of the heat, given in the cooling tower by water and received by air,is presented in the following form:

$$Q = c_l\left[\mathrm{G}_1(\mathrm{t}_1 - \mathrm{t}_2) + G_\mathrm{e} t_2\right] = \mathrm{G}_{\mathrm{m.c}}(i_2 - i_1) \quad (5)$$

The material balance (balance of moisture) is defined by equality between amount of the evaporated liquid and an increment of moisture content of air:

$$G_e = G_{m.c}(x_2 - x_1) \quad (6)$$

In case of thermal calculation of cooling towers expenses and initial parameters of water and air are usually set, and the final parameters t2, i2, h2 remain unknown. It is obvious that two equations (5) and (6) for their determination aren't enough. Therefore it is necessary to address the equations describing process of a heatmass exchange between water and air in a cooling tower sprinkler. They can be constituted only in a differential form, as the entering parameters change on the way of movement of water in a sprinkler all the time.

For elementary amount of a sprinkler of dV with a single area and height of dh (fig. 1) we have

$$dQ = \alpha(t - \vartheta)dV + i_v'' \mathrm{dG}_1 \quad (7)$$

where $\mathrm{i}_\mathrm{v}'' = c_l \mathrm{t} + r$ - steam enthalpy at water temperature t_1.

Determination of an average difference of enthalpies of air and sizes A and m

Calculations of cooling towers and handling of results of their researches on the given formulas require big costs of time and use of iterative methods. Therefore it is reasonable to make such calculations on special computers, for handling of results of measurements in case of determination of sizes A and m. For determination of the cooling capability of a sprinkler the following parameters are measured: speed of movement of air in the free section of the cooling tower over a sprinkler with, m/s; density of irrigation of q_l, m3 / (m·h); temperature of hot water at the entrance to the cooling tower t1, °C; temperature of chilled water at the exit from the cooling tower t2, °C; barometric pressure of P_b, mm of mercury; air temperature on dry ϑ and wet-bulb thermometersτ, °C. Besides, the area of the sprinkler, m^{2}and its height *h*, m is measured.

Basic data

The estimated dependences reflecting or determining operation of the cooling tower include the following sizes: water consumption; air consumption; temperatures of the entering and coming out water; estimated atmospheric parameters (climatic conditions) determining an enthalpy and density of the entering air, and also the limit of chilling of water in the cooling tower; technical characteristics on a sprinkler; area of irrigation of a sprinkler (cooling tower).

Depending on a calculation task one of the specified sizes can be required, and the others are set. At the same time climatic conditions (calculated atmospheric parameters) shall be always set.

The water consumption (hydraulic loading G_l) is usually set by technologists of production proceeding from heattechnical calculations of the equipment cooled by water – condensers, refrigerators, compressors, various technological devices, metallurgical aggregates, etc.

The air consumption (estimated air supply by the fan) is determined by aerodynamic calculation of the cooling tower.

Temperatures of the entering t1 and the leaving water t2 are established by technologists of production based on heattechnical calculations taking into account characteristics of the cooled equipment. It must be kept in mind that temperatures of turnover water, especially t2, can have very significant effect on parameters of engineering procedure, the sizes of cooling towers, diameters of pipes, displacement of pumps and performance of other equipment, and also on electricity consumption. Therefore it is reasonable to determine t2, and also consumption of the cooled water G_l by technical and economic calculations of joint operation of all constructions of a water turnover cycle – processing equipment, cooling towers, a circulating pumping setup and installations for cleaning and water preparation. However these calculations aren't always feasible. In this case when designing it is recommended to accept the calculated value of t2 proceeding from the condition that the difference t_2-τwas at least 5 °C. The lowest values of a difference t2 – τ can be accepted only in that case when it is dictated by strict requirements of production. For economical and practical reasons in all cases the difference t_2- τ should not be less than 2 °C.

Calculated parameters of the atmospheric (entering) air are set according to data of meteoconditions. Technical characteristics of the sprinkler (A, m, $\zeta_{c.o}$ and K_{sp}) are accepted by results of its researches. The area of the sprinkler (the cooling tower, section) is determined by calculation, but can be is set (depending on purpose of calculation).

Calculation methods

Technological calculations of cooling towers need to be made in case of development of new constructions, matching and conversion of projects (standard or other ready), for a binding to conditions of the specific entity, in case of job evaluation of the operating cooling tower in use and reconstruction.

Three types of calculations are most often carried out: determination of temperature of water cooled on the cooling tower t2, density of irrigation and the area of irrigation of the cooling tower F. The specified required parameters are from the joint decision (8) and (9). Depending on purpose of calculation the structure of basic data and the applied calculation formula change.

Determination of t is made by the formula

$$t_2 = t_1 - A\lambda^m hK\Delta i_{aver} / c_l \quad (8)$$

The area of irrigation of section or the cooling tower, climatic conditions (ϑ,τ, φ, P_b), technical and constructive characteristics on a sprinkler are set (A, *m,* ζ_{sp}, K_{sp}, *h,*q_l).

Calculation of q_l is made by the formula

$$q_l = \beta_{xv} / (A\lambda^m) \quad (9)$$

Air parameters when calculating cooling towers

Cooling towers are calculated usually on adverse atmospheric conditions for work in summer months of year. However it is inexpedient to conduct calculation on the most high temperatures and humidity of external air as they can be observed within a year only very shortly. The higher estimated temperatures and humidity of atmospheric air, the larger sizes the cooling tower is required and respectively the higher costs for its construction. At the same time too low estimated temperatures and humidity of air can lead to the fact that the actual water temperatures at the exit from the cooling tower during the long period in hot season will exceed the estimated temperature t2. It will entail undercooling of a production product in the heatexchange equipment. Therefore, in case of the choice of calculated parameters of external air it is necessary to take into account admissible temperature increase water t2 over estimated from conditions of engineering procedure of production, but to limit the period of this increase.

When calculating cooling towers it is recommended to proceed from average daily values of temperature and humidity of atmospheric air in summer months on long-term observations. As estimated values usually are accepted such values,which exceed average daily values within no more than 5 days in a year, and in case of less strict requirements – within no more than 10 days in a year.

For determination of calculated parameters of external air it is possible to use the available tabular data or curves of duration of average daily temperatures standing and humidity of atmospheric air for the construction area of the cooling tower according to long-term observations (not less than in 5-10 years). In the absence of ready data it is possible to make previously for constructing of duration of standing of temperatures of external air tables of average daily temperatures distribution and on zones, for example, through 1 °C and average daily humidity on zones through 5%. Further, conforming requirements of technological process, it is necessary to set number of days in a year *n* during which excess of the actual values is admissible, both over settlement and by curves to determine settlement temperatures and humidity of atmospheric air.

Average daily temperatures and humidity are calculated according to evenly even measurements of these sizes during the day: in 9, 12, 15 and 18 h. For the purpose of saving of time when handling materials of long-term observations usually are built curves of duration of standing ϑ and τ (or φ) only for the summer period (~ 100 days) and proceeding from this security are determine, %. Sites of such curves in the limits, that are used for the choice of estimated parameters of air, can be considered with sufficient degree of accuracy showing the standing's duration of the corresponding temperatures during the whole year, as in the rest of the time of year these temperatures don't repeat at all or are observed very shortly.

The stated method of determination of estimated parameters of atmospheric air requires big costs of time and work. Besides, basic data aren't published and they should be received in hydrometeorological service.

Air temperature according to moistened thermometer τ is a theoretical limit of chilling of water in the cooling tower. Considering that with approach of settlement water temperature to a theoretical limit of chilling τ the larger size of the cooling tower will be required, in case of their designing it is recommended to accept the settlement temperature of t2-τ proceeding from a condition: the difference t2 – τ shall be at least 4 °C for ventilatorycooling towers and 8 °C for tower. Lower values of differences t2 - τ are accepted only when it is dictated by requirements of engineering procedure of production.

With approach of t2 to a chilling limit the required cooling agent sizes strongly grow. Quite often, however, in case of setting of basic data for specific production put too low ("with an inventory") temperature of chilled water t2, reducing at the same time the difference t2 - τ . For cooling towers this reduction from 10 to 5 °C results in need of decrease in the water of density of irrigation $q_ж$ which is required for chilling by 2-2,2 times. Performance of ventilatorycooling towers under existing conditions decreases, as requires for increase in their area in order to chill the specified amount of water. Therefore it is not recommended accept too small value t2 - τ without special need. Conditions, when t2-τ≈At, are considered as optimum conditions for operation of vaporizing cooling towers.

Influence of barometric pressure at its usual values fluctuating within about 720-760 mm of mercury, it is rather small, and it can be not taken into account at practical calculations of cooling towers. However for mountain areas where barometric pressure can go down to values of 600-650 mm of mercury, it is already necessary to consider its influence. Decrease in barometric pressure leads, under other invariable conditions, to some decrease in intensity of vaporizing cooling, but in case of ventilatorycooling towers it is compensated and is even blocked by reduction of resistance of the cooling tower and increase in speed of air owing to reduction of its density. In cooling towers the reduction of a difference of density of the arriving and leaving air involving reduction of driving force , appears more considerable than reduction of absolute values of air density , and at decrease in barometric pressure cooling effect of the cooling tower decreases a little.

Determination of air consumption in ventilatorycooling towers

The task of determination of air consumption can arise during designing and binding of cooling towers, and also during operation for work on reconstruction. For this purpose aerodynamic calculation of the cooling tower are made. For its accomplishment it is necessary to know type and design of the cooling tower, brand of the fan, the main sizes of the cooling tower (section), its entrance windows, air distributor, sprinkler, water distributor and water catcher. It is also useful to have the factory graphical characteristic of the fan representing dependence between air supply, the created pressure, capacity and efficiency of this fan.

In this section the advanced method of calculation of supply of cooling towers fan is stated. The formula for determination of complete aerodynamic resistance of the cooling tower is corrected. The sizes entering it are brought into accord with really significant and measured sizes.

Availability of zones of turbulences on the areas of cooling tower irrigation and their influence on supply of the fan is considered. Factory graphical characteristics of cooling towers fans are presented analytically in the form convenient for calculations on PC. Examples of calculations of air expenses in standard cooling towers are given.

Materials of natural and laboratory researches allow express the general resistance of section of the cooling tower as follows:

$$P_R = (P_{ECT} + P_{SP} + P_{WD} + P_{WC} + P_{AA})\Phi + P_A, \quad (10)$$

where resistance of elements of the cooling tower are designated: P_{ECT} - an entrance to the cooling tower, including the air distributor, taking into account turn of air stream in the sprinkler; P_{SP} – a sprinkler; P_{WD} – water distributor; P_{WC} – water catcher; P_{AA} – approach of air to the fan on the way from the water catcher to the feedwell; P_A – resistance added when giving on the water cooling tower. This resistance depends on hydraulic loading, type of a sprinkler, water distributor and the sizes of section; Φ – the coefficient considering influence of the section form in the plan for the general resistance of the cooling tower. Calculation of resistance of section, kg/ m^2, is made by the formula

$$P_R = \frac{\gamma\omega^2}{2g}\zeta_r, \tag{11}$$

where ω – the speed of the movement of air in the free cooling tower section , m/s; γ – density of air, kg/m3, is accepted the same as specified in the characteristic of the fan, is usually equal to 1,2 kg/m3; ζ_r – the cooling tower section resistance coefficient determined by the formula

$$\zeta_r = \sum\zeta = (\zeta_{ECT} + \zeta_{SP}h + \zeta_{WD} + \\ +\zeta_{WC} + \zeta_{AA})\Phi + \zeta_A, \tag{12}$$

where coefficients of resistance ζ are designated by analogy with standard projects. All of them are dimensionless, except for coefficient ζ_{SP} which as it is accepted, has dimension 1/m; h – height of a sprinkler, m.

Ventilatory installations

One of necessary conditions of effective operation of cooling towers is the right choice of economic fans.

For cooling towers the special axial exhausting or delivery fans are usually used. In case of use of exhausting fans more uniform air distribution on cross section in the cooling tower bottom is provided, than when using delivery, as the input of air and its turn at right angle for movement up is performed at smaller speeds. Reduction in the rate of air movement in case of an entrance is reached due to implementation of entrance windows of big section from all or from two sides of the cooling tower. Uniformity of air distribution is an important factor in receipt of cooling effect of the cooling tower.

In case of the exhausting fans there are less opportunities to cooling tower, in its entrance exhausting fans throw out air with a speed of 6-10 m/s up, and (by observations of operation of the operating cooling towers) the vertical direction of a flow of damp air after fans remains on the site 10-12 m high that almost excludes a possibility of air recirculation. In case of delivery fans air goes out of the cooling tower with a speed about 1,7-2,5 m/s, and comparably light breeze can lead to blowing of outgoing warm damp air and to exhausting by fan that leads to sharp deterioration in cooling capability and requires increase in the sizes of the cooling tower.

In fig. 2 the scheme of the fan's arrangement in the cooling tower 77-Z-001 is provided.

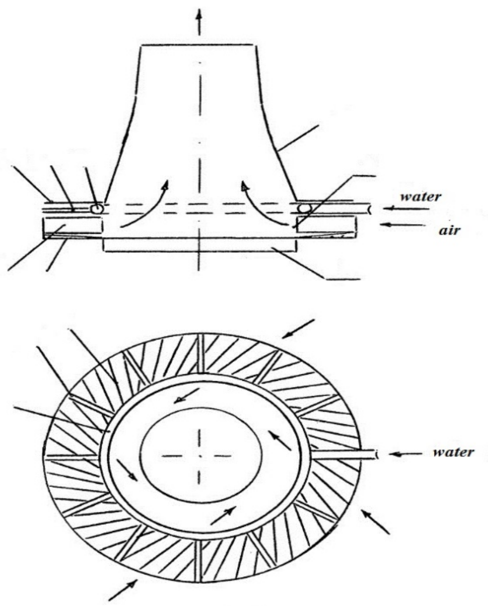

Figure 2 – Scheme of arrangement of the cooling tower fan 77-Z-001

Each section of the cooling tower 77-Z-001 is equipped with the axial fan. Its blades of an aerodynamic form are designed taking into account assurance of silent work. The step of blades is regulated manually and they are easily established in a nave by means of U-of figurative bolts and flanges depending on the chosen manufacturer. The fan has the drive from reducers with the double reduction and helical conic transfer located perpendicular to the fan axis. Reducers are established at the center in the fan case, and the nave of the fan is mounted directly on vertically located low-speed output shaft. Shaft of floating type are used. These shafts are made of composite material and established in flexible couplings from stainless steel. Electric motors are established outside of a ventilatory tower on a vertical platform.

Conclusion

Ventilatorycooling towers are the central and major link of a technological chain of heat removal in water turnover systems of the entities as by evaporation and heat exchange with atmospheric air, they allow to reduce water temperature to required values. It is also important to know that, when changing the speed of rotation of the cooling tower fan, it is possible to regulate output parameters of water recirculation depending on seasonal, meteorological and technological changes of a large number of factors.

This scientific article considers calculation of the ventilatorycooling tower and its installation, often used 3 types of calculation: determination of temperature of chilled water in the cooling tower, the irrigation density size, calculation of the area of the cooling tower sprinkler and information about 77-z-001 type of the ventilatorycooling tower. At present studying methods of determination of calculation algorithms of the ventilatorycooling tower, the program in the C# language which determines its performance is developed. In the developed program by means of the database it is possible to obtain full information on amount evaporation during water chilling, aerodynamic calculation, parameters of the air when calculating the cooling tower, air consumption, water consumption, water temperature during the delivery and pouring out, parameters of atmospheric estimation with climatic conditions, technological parameters of the sprinkler in the form of the table.

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