The structure optimization design of evaporative condenser

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Keywords: Number of entropy generation units; Principle of heat and mass transfer; Structure optimization; High efficiency compound evaporative condenser

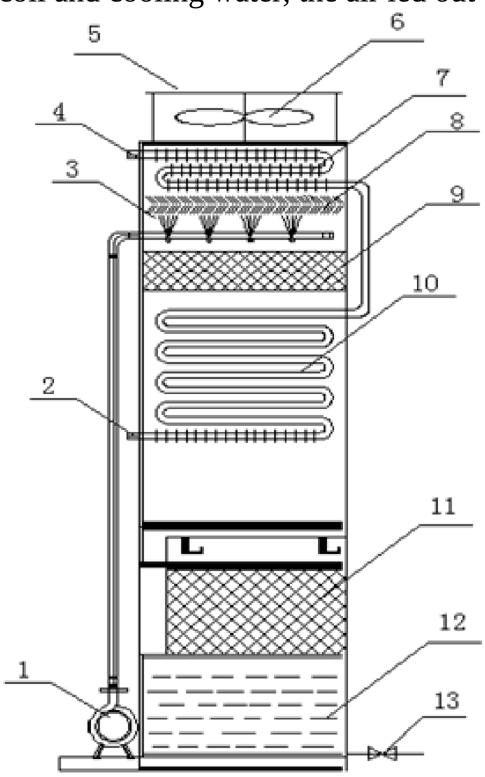
Abstract. Based on the structure of traditional evaporative condenser, by analyzing the number of entropy generation units and the principle of heat transfer and mass transfer, through three ways to optimize and improve the evaporative condenser: nozzle spray upward, arrangement of double layer inorganic filler and smooth circular tubes of bottom evaporative coils are replaced by low-finned elliptical tubes. Through the optimization and improvement, the structure is more compact and the heat transfer effect is enhanced, not only greatly improves the performance of the evaporative condenser, and the cleaning operation is simple, equipment is less noise. At the same time, analyzing the application prospect and the market of high efficiency evaporative condenser, and it is pointed out that the research and development of high efficient and energy saving new product has considerable economic benefits, environmental benefits and social benefits.

Introduction

At present, supporting for green energy-saving projects in China continue to increase, bring new vigor and vitality for development of efficient and energy-saving products, and the upgrade of original low efficiency and high pollution product. In oil refining, chemical industry, metallurgy, power, refrigeration and other industries[1], condensing and cooling water consumption accounts for about 80％of the industrial water consumption. There is great potential for energy and water saving in the process of all kinds of working medium condensing and cooling[2].The use of evaporative condenser reduces the industrial water consumption, avoids the industrial water pollution, and alleviates the problem of water shortage. Now the market mainly consists of three types of condenser: water cooled condenser, air cooled condenser and evaporative condenser. The evaporative condenser is a kind of efficient new energy saving and cooling equipment, the temperature of the medium outlet can reach the wet-bulb temperature of environment. It combines heat transfer and mass transfer process and has the advantages of high heat transfer efficiency, compact structure, less water consumption, low operation cost and convenient maintenance, and so on. Future market demand for evaporative condenser will continue to increase, so the improvement and development of high efficiency, high performance of evaporative condenser is goals of almost all engineering design personnel. Based on the research of evaporative condenser in the domestic and foreign research institutions, an efficient composite evaporative condenser is proposed, enhancing the effect of the heat transfer, compacting the structure and energy saving effect is more obvious, and provide the reference for the original equipment modification and new equipment research simultaneously[3].

System description

Figure 1 is structure diagram of high efficiency compound evaporative condenser, the working process is: putting the cooling water from the sink to the water spraying device using the circulating water pump, the cooling water is sprayed upward by the nozzle, the droplets will fall down after reach the highest point of potential energy under the action of inertial force, sliding to the upper filler and forming water film on the surface of the filler. Under the action of gravity, the water that absorbs heat to slide down to the inorganic filler, and makes full contact with inorganic filler, forms a certain thickness of water film on the filler surface, radiates heat, eventually flows back into the sink and into the next cycle. In this process, the air is sucked out of the window by the fan, passes the horizontal serpentine coils and packing, finally discharges from the outlet. The cooling water absorbs the heat of the high temperature medium in evaporative coil by tube wall and evaporate, at the same time makes convective heat transfer with the outside air that through the evaporative tubes and flow upwards[4]. Water has a larger latent heat of vaporization (About 2430.2kJ that 1 kg water vaporization will absorb heat under normal atmospheric press), thus the heat transfer outside tube getting strengthen by the water film evaporation and vaporization of the evaporation coil outside surface, and improving the total heat transfer efficiency obviously. The existence of the ripple filler, increases the contact surface area of air and cooling water, the temperature of water film is reduced, and the heat transfer temperature difference increases[5]. The fog catchers' effect is to reduce the spraying loss of cooling water, at the same time, dry air cooling section of fin and adjacent equipment corrosion degree caused by water mist will be reduced, the amount of dirt of the high temperature of fin tubes' surface will reduce. Outside air in contact with the water film of finned tube outer surface at the bottom of evaporative tube at first, increasing humidity, reducing temperature, so, during the heat transfer process, the temperature difference increases, the effect of heat transfer is enhanced. After absorbing heat of heat exchange coil and cooling water, the air led out by the fan.



1.Circulating water pump 2.Outlet of medium 3.Water spray device 4. Inlet of medium5.Outlet of air 6.Fan 7.Wave finned tube 8.Fog catcher 9.Upper filler 10.Wave smooth tube 11.Lower filler 12.Water tank 13.Water supply valve

Figure1. Structure diagram of high efficiency compound evaporative condenser

Optimization analysis

Fundamental principle

The optimal design of evaporative condenser is related to physical and geometrical parameters, which includes specified data and not specified data, according to the optimization to the not specified data, the optimal value of objective function are obtained, the not specified data is the design variable. In this paper, the optimal design of evaporative condenser, set the heat transfer performance as objective function, the velocity of fluid, spray density and temperature of air is design variable[6]. The objective function F(x) is that:

$$\mathrm{F}(x) = F(x_1, x_2, ..., x_n) \quad (1)$$

The precondition of selecting optimal scheme is to select the design variables under the constraint conditions, the constraint condition including equality constraints and inequality constraints. The general form of optimization problem is that: , its constraint condition is that:

$$h_i(X)=0(i=1,2,...,m) \tag{2}$$

$$g_i(X)\leq 0(j=1,2,...,n) \tag{3}$$

The matrix composed of design variable written as , the corresponding of , , and and the variation of is different, so the optimization can be divided into a variety of situation, the optimization of this paper include in nonlinear optimization.

Based on the second law of thermodynamics, the heat transfer of evaporative condenser is studied, due to the temperature difference between cooling water and cooling medium, and the consumption of pressure in the process of flow, must not a reversible process of entropy. Despite the heat and resistance are not the same form of energy, but two kinds of energy could study through the entropy production. Bejan A proposed a evaluation index of heat exchange equipment performance—the number of entropy production [5-6]. It is expressed as the ratio of entropy increase caused by the heat exchange equipment irreversible and large heat capacity of two heat transfer fluid:

$$N_s = \Delta S / C_{max} \tag{4}$$

The expression of heat transfer model's is that:

$$N_s = \frac{\dot{m}}{\rho q}\left(-\frac{dp}{dx}\right)+\frac{\Delta T}{T}\left(1+\frac{\Delta T}{T}\right)^{-1} \tag{5}$$

Among them: —mass velocity; —the unit heat transfer; —fluid density; —fluid pressure; —heat transfer temperature difference; —fluid absolute temperature.

By analyzing the formula of , we can know, the right side format part of equation is the action of entropy increase in caused by frictional resistance , the second part is the action of entropy increase in caused by heat transfer temperature difference. in the large case, also get bigger, and then the irreversible loss in the heat transfer will increase. If tends to 0, indicates the equipment for heat and mass transfer are closed to the ideal situation, heat transfer performance is better. Using the number of entropy gained unit is able to provide guidance to improve the equipment for heat and mass transfer, to make it more approaching the ideal condition of thermodynamics. As is put forward, linking , and entropy of system, it is an important breakthrough that turn into quality level of energy from order of magnitude of heat transfer performance evaluation indexes.

Program of structure improvement

Through the analysis of the number of entropy generation units, it can be concluded that: if the evaporative condenser heat transfer performance is improved, need to increase the temperature difference of cooling medium in the tube with cooling water and air out the tube. The medium inlet temperature is constant, so the optimization scheme can be adopted to reduce the temperature of the outer cooling water and air. In this paper, on the basis of the original evaporative condenser, improve it from three points on the structure:

(1)Optimization of spray device

In the traditional evaporative condenser, the heat transfer effect of single nozzle is better in the reverse direction; in the condition of two rows of nozzles, spray opposite is better than two rows inverse spray, this is because that spray opposite will make cooling water relatively uniform coverage in the evaporation coil section[7]. This article proposed an optimization scheme for the spray direction of evaporative condenser, all the nozzle spray water upwards, as shown in figure 2. After the cooling water is ejected from the nozzle, the majority of the cooling water falls on the lower part by self gravity, the small part of it upward flows due to the effect of wind, contacting with the fog catcher, the accumulation of droplets down to the coil.

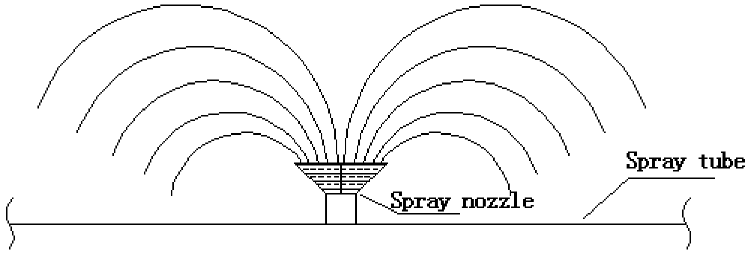


Figure2. Diagram of evaporative condenser nozzle and spray

Using this way to spray water, reduce the spray water on the impact of the packing, at the same time, reduce the noise of cooling water and packing, the existence of packing also avoids the covered effect of cooling water is not good[8]. The dirt and other impurities of the cooling water in the bottom of spray pipe, the way of spraying water upwards can reduce the possibility of nozzle blockage effectively, and sets a drain valve in the end of spray tube, the accumulation of dirt in the spray tube can be clean up regularly, operation is simple and convenient. When the nozzle spray upwards, the droplets will rise to location of potential energy maximum, and then fall down rely on gravity under the action of inertial force and air flow. As shown in figure 3, closing to parabolic shape. Compared with the way of spraying downward, prolonging the contact of droplets and air flow, due to water vapor partial pressure difference of droplet boundary greater than that of wet air, so a longer contact time make the external surface of droplet evaporation increased, and reduce the temperature of droplet, making the bigger temperature difference in the later process of heat transfer and improving the heat transfer efficient of evaporative condenser.

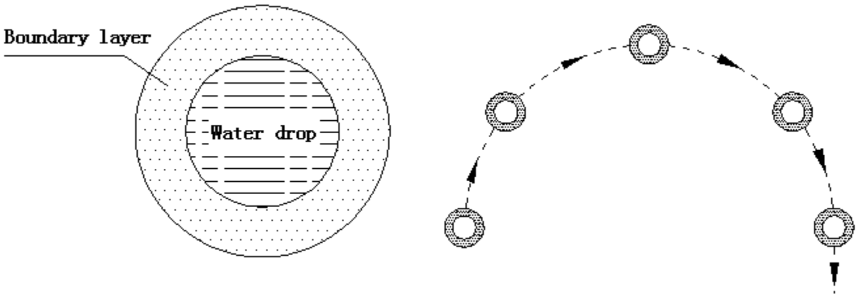


Figure3. Diagram of nozzle droplet's motion

(2)Packing film improvement

Adopting the inorganic polymer composite filler GLASdek which has characteristics of flow stability, small resistance and strong corrosion resistance, its matrix is glass fiber, after special resin foam, and then sintering it. Adding fillers in the middle of the spraying device and the evaporating coil pipe section, the cooling water from the spray, and gradually through the packing and evaporative coil tube, the water film formed in the packing surface with the air introduced by fan have a heat and mass transfer[9]. Setting of double layer packing, increases gas-liquid contact surface area, reduces the temperature of cooling water much faster, for the next of evaporative tube heat transfer provides a larger heat transfer temperature difference, increasing the heat transfer efficient significantly.

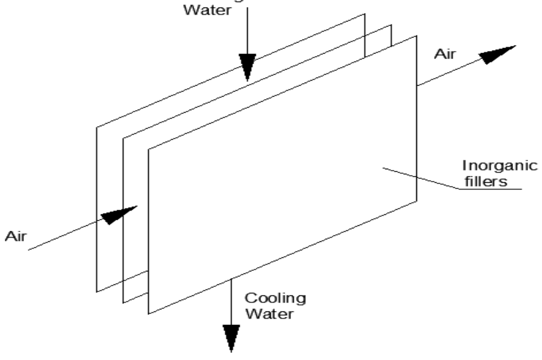


Figure4. Diagram of filler working principle

Table1 National air conditioning inspection center test results of tree kinds of fillers

Filler type	Before add filler			After add filler		Results of test		
	Dry-bulb temperature (˚C)	Wet-bulb temperature (˚C)	Wind speed (m/s)	Dry-bulb temperature (˚C)	Wet-bulb temperature (˚C)	Temperature difference (˚C)	Humidification capacity (g/kg)	Wind resistance (pa)
Organic	40.02	24.99	2.59	32.66	25.48	7.36	4.06	36.8
Inorganic	40.06	23.54	2.45	29.58	23.74	10.48	9.70	26.7
Metal	40.01	23.50	2.61	37.10	25.01	2.91	3.63	38.4

As we can know from the table 1[10], humidification capacity of inorganic filler is 9.7 g/kg, wind resistance is 26.7 Pa, two indicators shows that compared with organic filler and metal filler, the inorganic filler has strong water-absorbing quality and small resistance, and its thermal performance is better. The use of inorganic filler, will greatly increase the contact area of cooling water and air, cooling water's capacity of absorbing and evaporating will increase, and its temperature will decrease, for the next heat transfer provide provide larger temperature difference, and reinforce its evaporative coil tube heat transfer effect.

(3)Optimization of evaporation tube

In view of the evaporation section heat transfer analysis, we can simplify it that using total heat transfer coefficient K to characterize the complex heat transfer process, and also satisfying the Newton cooling formula

$$A = \frac{Q}{K \cdot \Delta T_m} \tag{6}$$

$$\Delta T_m = \frac{(T_1 - t_2) - (T_2 - t_1)}{\ln\left(\frac{T_1 - t_2}{T_2 - t_1}\right)} \tag{7}$$

Among them: *K*—total heat transfer coefficient; Q—total heat load; A—area of heat transfer; ΔT_m—logarithmic mean temperature difference; T_1—medium inlet temperature; T_2—medium outlet temperature; t_1—air inlet temperature; t_2—air outlet temperature.

By the above two formula, heat exchange capacity Q remain stable, to reduce the surface area of heat transfer, which increases effect of heat transfer equipment, depending on total heat transfer coefficient K and logarithmic mean temperature difference, for the same type of evaporative condenser and same flow condition, the K is certain, therefor, it is necessary to seek effective ways to increase the ΔT_m [11]. The medium's import and export temperature must meet the process requirements, and can't change one feasible way is that reducing the inlet temperature of air. As shown the figure of enthalpy-wet, the bigger relative humidity air, under the condition of constant enthlpy, the air temperature is low, to increase the inlet air humidity, can replace a line of smooth tube at the bottom of evaporative coil by the low finned elliptical tube, increasing the area of air and water heat transfer[12]. At the same time, a large part of cooling water attached to the surface of finned tube, reducing the influence of gas flow and the area of droplet ventilated, the wind resistance also is reduced, so the fan energy saving effect is obvious. In the process of operation, nearly three-quarters of the scale in the finned tube surface are adsorbed[13], the finned tube is at the bottom of the evaporative coil, it is easy to clean and operate.

Conclusion

Based on the analysis of the structure and heat transfer principle of evaporative condenser , some improvements are made on its structure, the change of spraying direction, which greatly reduces the noise level; the reasonable arrangement of high efficiency inorganic filler greatly reduces the temperature of circulating cooling water and enhances the effect of heat transfer; the smooth round tube at the bottom of evaporative coil is replaced by the elliptical finned tube, the temperature of inlet air is reduced, and the heat exchange efficiency of the system is improved, at the same time, making the device more compact, more convenient cleaning operation, the wind resistance is reduced, the fan is more energy-efficient. The evaporative condenser has its own unique advantages, so that it have a broad prospect in today's advocating resource-conserving society, improving and developing new efficient evaporative condenser has a long-term practical significance.

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This work was financially supported by the Harbin University of Commerce doctoral research start project (Item No.: 14LG21).