The discussion on cooling optimization of natural draft wet cooling tower

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Abstract. With the development of society, large capacity and super large capacity thermal power units have gradually become the main force of China's electric power industry. How to improve the efficiency of power plant units has become increasingly important. Effectively increasing the cooling efficiency of cooling towers can reduce the temperature of cold sources and improve the efficiency of the units. This paper introduces the development of the cooling tower and the internal structure and working principle of the cooling tower. Combined with the existing optimization methods of several cooling towers, the feasible direction of the optimization design of the cooling tower is put forward to provide support for finding the new energy saving technology to enhance the heat and mass transfer of the circulating water and air to further reduce the water temperature of the tower.

1. Introduction

Energy is the basic motive force of economic development and social progress, and it is an indispensable element of human existence. Therefore, the importance of energy is self-evident. In the energy composition of our country in recent years, fossil fuels such as coal still occupy the leading position. In the two sessions of 2017, Premier Li Keqiang put forward higher requirements for the state's energy use and pollutant discharge. China's "13th Five-Year plan" formally proposed the dual target of medium energy consumption and total coal consumption. That is to say, by 2020, the total energy consumption will be controlled at 48 billion tons of standard coal, and the total amount of coal consumption is controlled at about 4.2 billion tons[1]. With the development of the society, the demand for energy is increasing and finding new energy is difficult, so it is imperative to develop new energy saving technology, which is to improve the energy utilization rate, reduce the energy consumption and reduce the energy loss and waste in each link. The power industry is the foundation and key component of our country's economy, and as the first big household of non renewable energy coal, it is an important part of energy saving and consumption reduction work to improve the power generation efficiency and improve the energy utilization rate of the thermal power plant.

Thermal power generation is based on the Rankine cycle. The fuel is burning out of heat in the boiler, and the water is heated by the constant pressure in the boiler and superheater to become superheated steam. The new steam at high temperature and high pressure enters the adiabatic expansion of the steam turbine, and the exhausted steam after doing work is discharged into the condenser to condense isobaricly. and the heat is exothermic to the circulating cooling water. The waste heat is carried through the cooling tower and then discharge to the atmosphere. For this thermodynamic cycle, the boiler is a high temperature heat source, and the cooling water is a low temperature heat source. The cooling tower absorbs the waste heat from the circulating cooling water coming out of the condenser. After cooling, the circulating cooling water is used as a cold source to absorb the heat from the exhausted steam from the steam turbine. When the temperature is raised, it enters the cooling tower to cool down, and then forms a cycle.

Therefore, the cooling efficiency of the cooling tower determines the temperature of the circulating cooling water. According to the expression of the heat efficiency of the Rankine cycle, reducing the temperature of the low temperature heat source can improve the thermal efficiency to achieve the purpose of saving energy and reducing the consumption.

2. Types of cooling tower and research significance

2.1. Type of cooling tower

Domestic condenser circulating water cooling method is divided into two types: the opening and the closing[2]. The open cycle is the use of a large amount of natural water in the river, lake and sea to cool the circulating water, and then the natural water carrying waste heat is discharged into the river, lake and sea again, which is also called direct current cooling. Because of the use of this method, sufficient water supply must be guaranteed, so there is a high requirement for the environmental location of the power plant, which is generally used in the thermal power generation in the south of the Yangtze River and in the coastal area. At the same time, because the natural water absorbs the waste heat of circulating water, the higher temperature will affect the ecosystem of the water, so the use is also controlled. Compared with the open cycle, the waste heat of the closed cycle is discharged into the atmosphere through the cooling tower, which has a low demand for the water source and does not have a negative impact on the surrounding environment, so the application of this method is more extensive.

According to the ventilation mode, the cooling tower is divided into natural ventilation cooling tower, mechanical ventilation cooling tower and mixed ventilation cooling tower. According to the contact mode of circulating water and air, the cooling tower is divided into dry cooling tower, wet cooling tower and dry wet cooling tower. According to the flow direction of circulating water and air, it is divided into countercurrent cooling tower, cross flow cooling tower and mixed flow cooling tower. In the dry cooling tower, the high temperature circulating water flows in the wing tube, which mainly depends on the temperature difference between the circulating water in the tube and the external air. Therefore, it does not cause the loss of circulating water due to evaporation in the evaporation process, which is suitable for the areas with relatively lack of water resources. However, the outlet temperature of dry cooling towers is rather high, and the manufacturing process requires a large number of metal fins and high cost. Therefore, in general, thermal power plants should use wet cooling towers as far as possible.

In this paper, the characteristics of natural circulation counterflow wet cooling tower are studied. During the operation of thermal power units, the natural circulation counter current wet cooling tower is a typical equipment for heat and mass exchange between gas and water. It is used to cool the circulating water from the condenser and transfer the low temperature heat released by the condenser to the atmosphere, in order to maintain the low temperature and vacuum state of the condenser and ensure the safe and stable operation of thermal power units.

2.2. Research significance

For a long time, the potential of low quality cooling circulating water is often ignored by people. In recent years, with the development of society, the capacity of thermal power plants has been increasing, and the cooling towers have also been developing to a large scale. The trend of cooling tower height in recent decades in China is shown in Table 1. The large-scale cooling tower will increase the cost of the power plant and prolong the construction period. In addition, the increase of construction difficulty will result the increase of non measurable safety factors. Improving cooling efficiency of cooling tower not only conforms to the policy of national energy saving and emission reduction, but also reduces the area of cooling tower. What's more, it can also reduce the height of cooling tower, reduce the investment of the power plant, and reduce the construction time.

Table 1. The change of the cooling tower height (m) with the year

Time	1960	1967	1966	1983	1987	1995	2008	2014
Hight	40	51.5	70	105	130	150	180	191

In normal operation of power plant units, especially in summer, the cooling efficiency of cooling towers is not ideal because of the high dry bulb temperature of cooling towers. However, the cooling capacity of the cooling tower is insufficient, the vacuum degree will be reduced, the temperature of the condenser inlet is higher and the vibration of the steam turbine may increase, which affects the safe operation of the units. In order to ensure the safe operation of steam turbines, power plants usually increase the load of circulating pumps or reduce the load of steam turbines. In this way, the cooling efficiency of the cooling tower is insufficient, which makes the extra electric energy consumed by the circulating water pump and even the unit can not run full load or high load. It is a waste of resources in the power plant.

Therefore, if we can proceed from the cooling tower cooling performance to optimize the energy saving, it will bring considerable economic benefits, so as to achieve the purpose of saving energy and reducing consumption. The cooling performance of the cooling tower directly affects the economy and stability of the thermal power units[2]. For the thermal power units, the reduction of the water temperature of the circulating water tower is directly proportional to the increase of the circulating heat efficiency. Li Xiuyun and so on analyzed the influence of the cooling tower outlet temperature on the efficiency of the units, and pointed out the energy saving potential of the cooling tower.

The specific data are shown in Table 2 as follows[3]:

Table 2. The economic change of outlet water temperature by rising 1 ℃

unit capacity (MW)	25	50	125	200	300	350	600
unit load (MW)	25	50	125	200	300	350	600
efficiency reduction (%)	0.451	0.381	0.31	0.328	0.23	0.242	0.21
coal consumption increment (g/kW·h)	1.94	1.52	1.003	1.107	0.798	0.738	0.462
Heat consumption increment (kJ/kW·h)	56.86	44.84	30.28	32.44	23.39	21.63	13.54
coal consumption increment (t/a)	340	536	904	1550	1676	1808	1940

In Table 2, the influence of outlet water temperature on the cooling tower energy consumption and the variation of efficiency of different units capacity when the outlet water temperature increase 1℃ are analyzed. For 600MW units, the corresponding cooling tower circulation water is about 70000t/h, and its energy saving potential will be further enhanced. The relevant data show that the efficiency of the corresponding medium pressure unit and the high pressure unit can be increased by 0.47% and 0.35% respectively when the water temperature drop 1℃. If the nuclear power can be used to generate electricity, the growing efficiency of the units can reach 0.7%[4].

3. Optimization of wet counterflow cooling tower with natural circulation

3.1. Principle of wet counterflow cooling tower with natural circulation

This paper mainly studies the natural circulation counterflow wet cooling tower, the basic structure and working process of the cooling tower, as shown in Figure 1 below, its structure includes the tower drum, the central shaft, the water separator, the water distribution system, the packing, the rain area and the collecting pool. The circulating water carrying waste heat from the condenser is sprayed to the filler through the water distribution system. Water is formed on the filler to form water film or water droplet to enhance the heat transfer rate with the air and extend the heat transfer time with the surrounding air. The circulating water after the cooling falls into the pool to return to the condenser for use. At the same time, the ambient atmosphere is entered by the bottom of the cooling tower, through the rain area and the packing, and the air is finally saturated under the actual temperature by the two phase heat and mass transfer. The air is discharged through the water removal device after water removal.

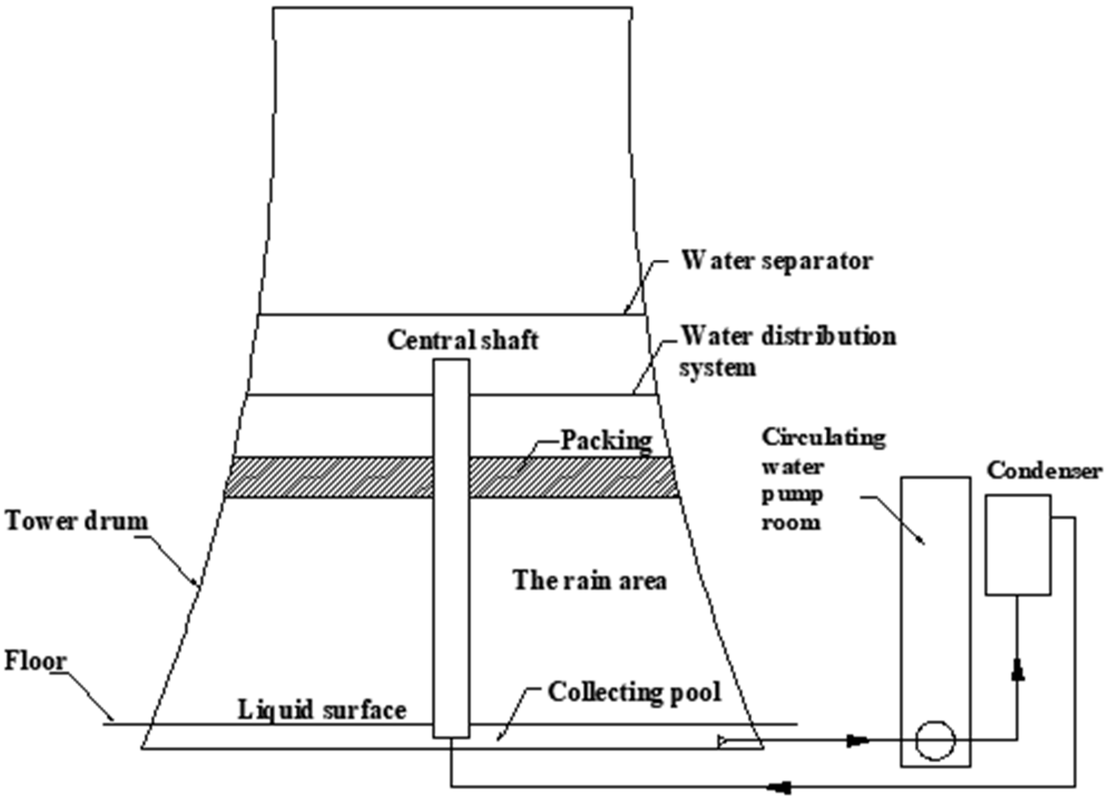

Figure 1. natural circulation counterflow wet cooling tower working flow.

The circulating water in the water distribution system is sprayed out through the nozzle, and the circulating water and the surrounding air are convective heat transfer. The sprinkler drops on the filler for two heat exchange. The water droplets will splash between the circulating water and the filling material, the shape of the filler and the different arrangement of the filler in the cooling tower will also form the water film, some of which are water droplets splashing and the convection heat transfer after forming the water film. The heat exchange process is the most complex, and the heat transfer time is the longest, and the heat transfer effect between the filler is strongest. Once the circulating water is distributed again through the packing, the distribution of the circulating water changes slightly and enters the rain area for third times of heat exchange. In this process, the air flow in the circulating water and the cooling tower is convective heat transfer. The air flow field around the cooling tower and the distribution of air flow in the cooling tower are uneven. The cooling efficiency of the cooling tower is greatly influenced by the distribution of circulating water. The circulating water in the rain zone releases heat through the three times heat transfer, and reduce the temperature. Finally, the circulating water enters the reservoir and carries out fourth evaporative heat dissipation, and then enters the condenser of the steam turbine to make the exhaust steam cool and coagulate.

3.2. *Optimization principle*

The cooling capacity of the storage tank in the cooling tower is ignored. In addition, the proportion of the cooling load in the area from small to large is water distribution area 5-10%, the rain area 20-30% and the packing area 65-70%[5], so the cooling performance of the water distribution area and the packing area has a great influence on the overall cooling efficiency. The cooling performance is influenced by many factors, and the relationship between various factors is also complicated. The optimal design of cooling towers can be achieved through the arrangement of circulating water distribution and changing the flow state of circulating water and air, so as to change the characteristics of heat and mass transfer between them and improve the cooling capacity of the cooling tower, and can also change the flow state between circulating water and air through the material, shape and arrangement of the packing, so as to change the heat and mass transfer characteristics between them and improve the cooling capacity of cooling towers. At the same time, fillers sometimes also play the role of water distribution. The cooling performance of cooling towers is also influenced by the environment, especially the influence of environmental crosswind. The existence of environmental side wind causes the uneven distribution of the flow field in the tower, which destroys the uniformity of the circumference, reduces the air inlet performance of the cooling tower and reduces the ventilation in the central area of the tower. Therefore, the cooling capacity of the cooling tower reduces. The air flow field inside and outside the cooling tower can be optimized by adding air deflector in the rain area or adding air supply pipe in the center of the rain area to enhance the cooling efficiency of the cooling tower. In addition, the collection tank can be moved upward, and the resistance of the rain zone can be reduced by reducing the height of the rain area, and then the ventilation quantity of cooling tower increases. Thus, the cooling efficiency of the cooling tower is improved. The high level water collecting natural draft wet cooling tower is a new cooling tower designed by this method[6].

4. Conclusion

There are two main problems in cooling towers: first, the ventilation volume in the central area of the cooling tower is small and the heat transfer capability is poor. Second, the environmental crosswind destroys the uniformity of the circumference inlet, resulting in an offset of the axisymmetric center and weakening the heat transfer capability. Through the study, it is found that cooling tower cooling optimization generally starts from the following aspects: 1. According to the air flow field in the cooling tower, the distribution of water distribution in the cooling tower is optimized. 2. According to the characteristics of the heat and mass transfer of the steam and liquid two phase flow, the structure and distribution of the packing and the material of the packing are optimized; 3. In the rain area, the air guide plate is added or in the center of the rain area, the air supply pipe is set up to optimize the air supply structure; 4. Raising the level of the water collection level to improve the air flow rate of the cooling tower. The study of cooling tower cooling optimization will provide technical support for improving the efficiency of thermal power generation and improving the utilization of energy, and provide technical reference and theoretical basis for the optimization of cold end system.

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