Research and Application of Evaporative Cooling Ventilation and Salty Moisture Corrosion Prevention Technology for Steam Turbine House

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Abstract. This paper focus on Pakistan Hub coal-fired 2×660MW power project which located in the coast areas with high temperature and high salty moisture. The category of corrosivity of atmosphere in Pakistan Hub is C5. The high salty moisture will increase the corrosion of indoor equipment and structures in turbine house, which threaten the safe and stable operation of power plant. Direct evaporative cooling (DEC) technology is used to cool the centralized supply air for the turbine building. To prevent the salty moisture air being supplied into turbine building causes corrosion for indoor equipment and structures, the desalting moisture filter has been developed and combined with the evaporating cooling unit, which realized the large-scale engineering application. The efficiency of desalting moisture filter reaches more than 93% tested in Tongji University and VTT in Finland, under the condition of the design outdoor temperature of 38.9 ℃ in Karachi, the supply air temperature is 24.4 ℃, which ensures the operating environments of working area and meeting the occupational hygiene requirements and anti-salt spray corrosion requirements.

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Introduction

The purpose of general ventilation of the steam turbine house is to eliminate the large amount of heat emitted by the steam turbine generator and auxiliary equipment, as well as the moisture generated during the production process and hydrogen leakage of the hydrogen-cooled generator, meet the industrial hygiene standards requirements, improve the operating environment around the equipment, and extend the service life of the equipment. "Code for Design of Fossil Fired Power Plants" GB50660, "Hygiene Standards for The Design of Industrial Enterprises" GBZ1 and "Code for Design of Heating, Ventilation and Air Conditioning in Power Plants" DL/T 5035 specified the requirements for ventilation in the steam turbine house. The ventilation for the steam turbine house should be determined by the indoor hygiene standards, process requirements, geographical conditions and surrounding environment, etc.

1 Project Overview

The 2×660MW coal-fired power project is located in the coastal area of Hub, northwest of Karachi, Pakistan, with a straight-line distance of about 33km from Karachi. The steam turbine house is about 300m away from the Arabian Sea. The seawater once-through cooling is adopted for the power plant units. The American standards and Chinese standards were using in project design. The project started in March 2017 and was putted into commercial operation in August 2019.

Fig. 1. Aerial view of the 2×660MW coal-fired power project.

1.1 Meteorological conditions

The nearest weather station is the Karachi Airport Weather Station. Karachi Airport is located in the southeast of the project site, and the straight-line distance from the site is about 47km. The meteorological data based on the ASHRAE weather data which extracted from the weather station from 1986 to 2010.

Meteorological data not guaranteed for 35 hours per year (0.4%) for ventilation and air conditioning design:

Dry-bulb temperature (DB) 38.9℃

Mean coincident wet-bulb temperature (MCWB) 22.7°C

Extreme maximum temperature 47.8℃ (1938.5.9)

Extreme minimum temperature 0℃ (1934.1.21)

The extreme maximum temperatures in the 5 years, 10 years, 20 years and 50 years before 2010 were 43.1℃, 43.8℃, 44.4℃ and 45.1℃.

1.2 Atmospheric salty moisture characteristics

Salty moisture is a dispersion system composed of tiny droplets of salt in the atmosphere. The main component of the salty moisture is NaCl, and the NaCl solution exists in the form of Na^+ and Cl^-. The deposition rate of the salty moisture is proportional to the concentration of Cl^-. It can be known from previous studies that the corrosion effect of salty moisture is affected by temperature and concentration of salt solution. When the temperature is up to 35 °C and the concentration of salt solution is 3%, its corrosion effect on objects is the greatest. The high concentration of NaCl in the salty moisture is rapidly decomposed into Na^+ and active Cl^-, which chemically react with very active metal materials.

1.2.1 Relationship between Atmospheric Chloride Ion and Season and Distance

The chloride concentration in different regions has a variation pattern of high in winter and low in summer. Generally speaking, the high chloride content in the atmosphere is from October to December, the medium content is from January to March, and the low content is from April to September. The chloride concentration fluctuates greatly throughout the year. Under the same climatic conditions, the distance from the coastline has a great influence on the change of chloride concentration. The closer to the coastline, the higher Chloride concentration[1]. When the distance is less than 95m, the atmospheric chloride content is above $2mg/100cm^2.d$. When the distance is between 95 and 235m, the atmospheric chloride content is $2mg/100cm^2.d$ and $0.2mg/100cm^2.d$. when the distance is greater than 235m, the atmospheric chloride content is below $0.2mg/100cm^2.d$.

1.2.2 Salty moisture corrosion characteristics

According to ISO9223-2012 " Corrosion of metals and alloys - Corrosivity of atmospheres - Classification, determination and estimation "[2], the corrosivity of the atmosphere is divided into six categories, which are C1, C2, C3, C4, C5, CX respectively. The category of corrosivity of atmosphere in Pakistan Hub is C5.The corrosion rates of metals for the first year of exposure for C5 corrosivity category are shown in Table 1.

Table 1. Corrosion rates of metals for the first year of exposure for C5 corrosivity category

Corrosivity category	Corrosion rates of metals r (microns metal/year)		
	Carbon steel	Zinc	Copper
C5	80<r≤200	4.2<r≤8.4	2.8<r≤5.6

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2 Ventilation system for steam turbine house

The span of the turbine house is 30.6m, the span of the deaerator frame is 9.0m, the frame of the coal bunker is 11.7m, the length of the turbine house is 155.5m, and the height of the turbine house is 30.8-32m. The coal bunker frames are separated by partition walls.
The maximum indoor temperature is design outdoor temperature+6 ℃ According to the ASHRAE HANDBOOK[3]. The ventilation system adopt the forced mechanical supply and exhaust system, the supply air temperature is 38.9℃, and the exhaust air temperature is 44℃. Considering reducing the total ventilation volume, reducing the initial investment and meeting the requirements of salty moisture removal, the evaporative cooling unit with the function of removing salt spray is used for mechanical air supply, and the FRP roof fan is used for mechanical air exhaust. The structure diagram of the evaporative cooling and desalting moisture unit is shown in Figure 2.

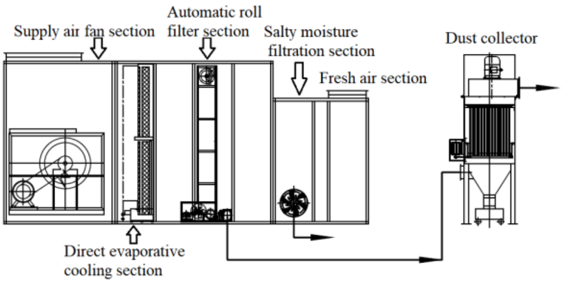

Fig. 2. The structure diagram of the evaporative cooling and desalting moisture unit.

The outdoor air first enters the salty moisture filter, and the salty moisture is discharged to the outside through the salty moisture exhaust fan. The air flow is then further filtered through the automatic roll filter, and then enters the inorganic glass fibre cooling pad, and is treated with water to achieve isenthalpic cooling of the air. The air with lower temperature is sent into the turbine house by the blower, and the hot air is exhausted to the outside through the FRP roof fan on the roof of the turbine house.
The air volume of a single the evaporative cooling and desalting moisture unit is 150,000m^3/h, of which 15,000m^3/h is removed by the salty spray exhaust fan, and the actual air supply volume is 135,000m^3/h. There are a total of 11 sets of evaporative cooling and desalting moisture units in the steam turbine house, and one of them is a standby unit according to the contract requirements. On the column side of row A, 2 units and 4 units are arranged on the 0.00m floor and the 6.9m floor respectively, and one unit on the 6.9m floor is in standby. On the column side of row B, 2 units and 3 units are arranged on the 0.00m floor and the 22.00m floor respectively. The total air supply volume is 135×10^4 m^3/h, and the air supply volume on the column side of B row reaches 50% of the total air supply volume, which meets the related requirements of "Design Regulations for Evaporative Cooling Ventilation and Air Conditioning Systems of Power Plants" DL/T5515-2016. The air supply volume of the 0.00m floor, the mezzanine floor and the operation floor is 41%, 41% and 18% of the total air supply volume.

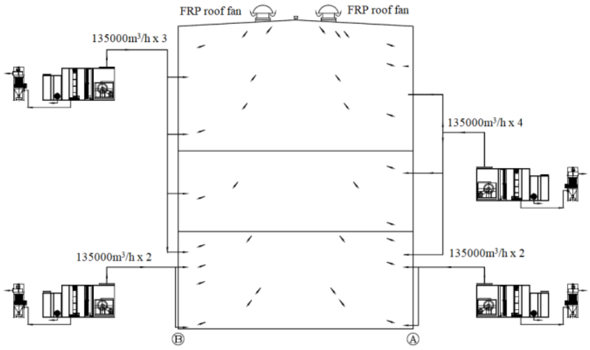

Fig. 3. The diagram of ventilation system for steam turbine hourse.

3 Evaporative cooling system

The dry-bulb temperature in the Karachi region of Pakistan is 38.9°C and the mean coincident wet-bulb temperature (MCWB) is 22.7°C, which is very suitable for evaporative cooling technology to cool the air sent to the turbine room.
Direct evaporative cooling is to use circulating water to fully contact the air directly in the cooling pad. Since the partial pressure of water vapour on the surface of the cooling pad is higher than the partial pressure of water vapour in the air, this natural pressure difference becomes the driving force for water evaporation. The evaporation of water reduces the temperature of both air and water, while the moisture content of the air increasing, and the sensible heat of the air is converted into latent heat, which is an isenthalpic cooling process. The evaporative cooling pad is made of glass fiber pad. Under the design condition, the sectional speed of the unit is 2.5m/s, and the specific surface area of the cooling pad is 440m^2/m^3. According to the empirical formula for calculating the thickness δ of the evaporative cooling pad:

$$\exp(-0.029 t_{wg}^{1.678} \times t_{ws}^{-1.855} \times v_y^{-0.97} \xi\delta) = 1-\eta \tag{1}$$

Where, t_{wg} is dry-bulb temperature outside, 38.9°C, t_{ws} is wet-bulb temperature outdoors, 22.7°C, V_y is air handling unit air speed, 2.5m/s, ξ is direct evaporative cooling pad specific surface area, 440m^2/m^3, and η is direct evaporative cooler saturation efficiency, 90%.
The thickness of the inorganic glass fibre wet film used in the evaporative cooling unit of this project is determined to be 300mm. Under the design condition that the outdoor design temperature in Karachi, Pakistan reaches 38.9°C, the supply air temperature reaches 24.4°C.

4 Salty moisture Filtration System

The salty moisture filtration system is the core of the steam turbine house ventilation with the evaporative cooling and desalting moisture unit. The desalting

moisture filter should meet the following four requirements.
Salty moisture removal efficiency, The salty moisture filter should have high salty moisture removal efficiency, especially the efficiency of capturing fine salt mist below 10 μm should not be less than 90%.
High reliability, It has a long maintenance cycle to meet the year-round operation requirements. The removed salt mist should be discharged in time.
Salty moisture corrosion prevention, the material of the filter element and rotating parts of the equipment has the characteristics of corrosion resistance, so as to avoid the salty moisture filter itself being damaged by the salt spray.
Lower resistance, the salty moisture filter has low resistance, and it does not increase the fan pressure and operating energy consumption of the desalting moisture evaporative cooling unit too much.
The new salty moisture filter is developed on the basis of the GRD automatic sand and dust air seperator.

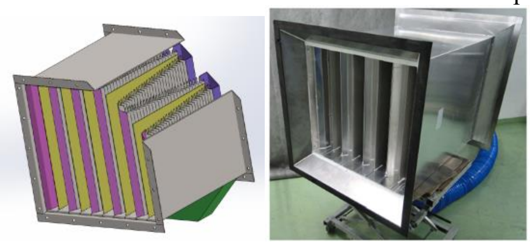

Fig. 4. The structure diagram of the salty moisture filter

The salty moisture filter device is composed of a salty moisture filter, a dust exhaust fan, an air valve, etc. The salty moisture filter device adopts a modular design, with a wedge-shaped blade inside, and each module is independently formed, which can be quickly replaced and maintained when needed.
In 2015 and 2016, the salty moisture filter was tested on the 1st generation and 2nd generation samples at the Shanghai Tongji Construction Engineering Quality Inspection Station of Tongji University and the Finnish VTT Expert Service Ltd respectively. The test conditions and main test results are shown in Table 2.

Table 2. Test conditions and main test results of salty moisture filter[4][5]

Item	1st generation sample	2nd generation sample
Test agency	Shanghai Tongji Construction Engineering Quality Inspection Station	Finnish VTT Expert Service Ltd
Test standard	"Air Filter" GB/T14295-2008	EN779-2012 《Particulate air filters for general ventilation-determination of the filtration performance》
Test particles	Potassium chloride smoke	ASHRAE 52.2. Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size
Test method	Counting method	Gravimetric method
Test air volume	3500m^3/h	3492m^3/h
Pressure loss	148Pa	110 Pa
Salty moisture removal efficiency	92.7% （≥4 μm）	≥93%

5 Conclusion

Focus on the characteristics that the 2×660MW coal-fired power project located in a hot and humid area with salty moisture corrosion, the new desalting moisture filter with continuous filtration and continuous salty moisture removal functions was developed, and the evaporative cooling technology was used to cool the air entering the steam turbine house. The temperature requirements and air quality requirements required by the workplace are guaranteed through good airflow organization, and the equipment, components and pipes in the steam turbine house are not affected by salty moisture corrosion. It has important reference value for the large air volume ventilation systems in coastal areas that need to remove salty moisture, such as the ventilation system of the steam turbine house of nuclear power plants and fossil power plants.

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