Optimization of Ventilation System for a Main Power Plant in an Underground Pumped Storage Power Station

Chentong Lei1, Desheng Xu1, Shan Feng2, Yanfeng Li1*, Huimin Lu1

1Beijing University of Technology, Beijing, China. 
2China University of Political Science and Law, Beijing, China.

Abstract. Pumped storage power station is an economic and reliable means of peak load regulation for power networks. The temperature and humidity control are complicated due to the huge amount of heat and moisture emission in the main power plant. This paper investigates the operating condition of three different ventilation cases in a five-storey underground pumped storage power station. A full-scale model of the main plant was built for numerical simulation. Three ventilation cases were studied by changing the number, area and layout of air supply vents at the top of the main plant. The airflow distribution of three cases in summer condition were calculated and an optimal ventilation case was determined by comparing the jet flow range and temperature in the working zone. The working condition in winter was also simulated and verified in order to ensure the reliability of the ventilation case. Results show that case 1 was determined as a reasonable air supply case. In this paper, a reasonable scheme of ventilation system was proposed in an underground pumped storage power station. The results would be helpful to optimize the air ventilation mode in underground powerhouse of pumped storage power station.

1 Introduction

The main structure of pumped storage power station is located deep underground and has tall building envelope. The main plant is composed of generator floor, busbar floor, turbine floor, volute floor and corridor floor. The mechanical and electrical equipment of the main plant is mainly installed in the generator floor, which emit a lot of heat when generating electricity. In order to ensure the normal operation of equipment and safety of staff, the ventilation system in the generator floor should be studied.

Ventilation system of hydropower station is mainly designed by means of arch crest air supply and sidewall return. Y.C Liu [1] et al. have studied arch crest ventilation system of powerhouses in Xiluodu. In addition, due to large underground space, unreasonable ventilation system will cause a huge waste of energy. R.Wan [2] et al. carried out numerical simulation to analyse the airflow of the tall space of underground power station. In recent years, with the development of the computer simulation technology, computational fluid dynamics has been more mature to study the airflow in the underground power station. H.L.Zhang et.al.[3] have studied large underground space air ventilation by changing the number, the arrangement and the velocity of supply air outlets, and the optimal design scheme was obtained However, there are few researches on the outlet parameters of the ventilation design scheme for a large tall building.

In this paper, a series of numerical simulations were conducted to study the optimal air supply scheme under different number, area and layout of air supply vents. The results provide reference for ventilation system design of underground pumped storage power station.

2 Physical model

The numerical model was built on the basis of the actual geometry of the main powerhouse as shown in Fig. 1.

![Physical model of powerhouse generator floor](https://example.com/fig1.png)

* Corresponding author: liyanfeng@bjut.edu.cn
return air outlets are arranged at the bottom of the sidewall. In winter mode, the generator floor receives high temperature exhaust air from the four outlets of bus tunnel, which are closed in summer. In summer, the design supply volume of fresh air is $20 \times 10^4 \text{ m}^3/\text{h}$. The air supply temperature is $15^\circ \text{C}$ and the relative humidity is $90\%$. The effective area coefficient is 0.7, and parameters of supply air vents are listed below.

| Cases | Number of vents | Diameter of vents (mm) | Supply air velocity (m/s) |
|-------|-----------------|------------------------|---------------------------|
| Case 1 | 30              | 600                    | 9.36                      |
| Case 2 | 40              | 600                    | 7.02                      |
| Case 3 | 15              | 849                    | 9.36                      |

### 3 Mathematical model

#### 3.1 Governing equations

The flow in large space belongs to incompressible turbulent flow. The governing equation is:

$$\frac{\partial \phi}{\partial t} + \nabla \cdot (\phi \mathbf{u}) = \nabla \cdot (\Gamma \nabla \phi) + \mathbf{S}_\phi $$

Where, $\phi$ is a universal variable, represent speed or temperature; $\Gamma$, generalized diffusion coefficient; $\mathbf{S}_\phi$, generalized source term.

#### 3.2 Meshing and Boundary conditions

The non-uniform grid method is used to divide the calculation area. in which the grid near the inlet and outlet is treated as $0.2 \text{ m}$, and the middle of the tall space is treated as $0.5 \text{ m}$. The entire spatial computing grid is about $1.6 \text{ million}$. In the iterative calculation process, the convergence standard is set to $10^{-6}$ for the residual of the energy equation, and $10^{-3}$ for the other equations.

Initial indoor temperature is $23^\circ \text{C}$, relative humidity is $72.5\%$, atmospheric pressure is $101325.0 \text{ Pa}$. The velocity of supply air outlets is set as $9.36 \text{ m/s}$, $7.02 \text{ m/s}$ and $9.36 \text{ m/s}$, respectively. The exhaust air outlet was set as $-19.6 \text{ Pa}$. The temperature difference between powerhouse and adjacent rooms is very small. The walls, the floor and the ceiling are set as adiabatic boundaries.

#### 3.3 Model validation

In order to verify the simulation results, the experiment of Li’s was chosen. Li [4] et al. (2015) has conducted a series of experiments to study the air distribution of large underground hydropower plants in pumped-storage stations. The main plant is $138 \text{ m} \times 24 \text{ m} \times 17 \text{ m}$ ($L \times W \times H$), and four heat source is placed at the centerline of generator floor. The supply vents are arranged in two rows, and spacings between the vents are $6 \text{ m}$.

In this validation study, we simulated the similar process. Fig. 2 presents the comparison, in terms of dimensionless distances, between the simulation results and experimental measurements. It can be seen that the simulation results are in acceptable agreement with the experiments, indicating that Airpak is applicable for simulations of air distribution of large underground hydropower plants in pumped-storage stations.

### 4 Results and discussion

#### 4.1 Summer condition

Fig. 3a–3c shows the speed profile of airflow at $z=6.9\text{m}$ of the three cases. Results show that the air velocity in the case 2 decreased due to the increase in the number of air supply outlets, under condition of same outlet area. Supply air velocity attenuates faster along the outlet to the working area, and an explicit inclined downward jet flow can be seen. As a result, most of jet flow range is too short to reach the working area. In case 1 and 3, large flow vortexes occur in most space of the room, so that the whole working area is in the backflow zone. The jet flow range can basically meet the requirements.

| Table 2. Requirements for hydraulic power plants in summer |
|----------------------------------------------------------|
| Temperature | Relative Humidity |
|-------------|-------------------|
|-------------|-------------------|

Fig.2 Comparison with Li’s experiment results

Fig. 3. Air velocity distribution on vertical plane ($z=6.9\text{m}$)
Fig. 4a~4c. show the simulation results of velocity at y=2m of the three cases. It can be seen that the air velocity in the working area of case 1 and 2 maintained at about 0.5 m/s. In case 2, the decrease in supply air velocity results in a more uniform distribution of air velocity. In case 3, the airflow uniformity in the working zone deteriorates, as the number of vents decreases. The air velocity below the air-outlet is higher than 0.8 m/s, while the air velocity in other areas is between 0.1 m/s and 0.5 m/s, implicating the poor air supply effect.

(a) Case 1

(b) Case 2

(c) Case 3

Fig. 4. Air velocity distribution on horizontal plane (y=2m)

(a) Temperature distribution

(b) Relative humidity distribution

Fig. 5. Temperature and relative humidity distribution of case 1 (y=2m)

Table 3. Air flow requirements for occupant zone

| Temperature | Velocity | Relative humidity |
|-------------|----------|------------------|
| 20-26℃     | 0.3~0.8 m/s | 60%              |

From Fig. 5a~5b, it can be seen that the average temperature and relative humidity under this condition are about 21.7℃ and 60.7%, which meet the requirements of the specification.

Fig. 6. shows the temperature distribution along the x direction of the three cases. As can be seen in case 2, the cold air jet flow has a weaker influence on the working area due to low supply air velocity, thus the temperature in the working zone being higher than that in case 1. In case 3, the air temperature in the working zone becomes more unevenly distributed due to the increased spacing between outlets. Therefore, based on the above analysis, case 1 with 30 swirl diffusers under the arch crest was the most reasonable air supply scheme.

Fig. 6 Air temperature distribution of three cases (y=2.0m)

4.2 Winter condition

For case 1, the temperature of the generator floor in winter is 15 ℃ and the relative humidity is 70%. According to the calculation results, under the condition of full load operation, the supply air is composed of 2.8°C 6.7 × 10^4 m^3/h fresh air and 30 °C 13.3 × 10^4 m^3/h exhaust air from bus tunnel. Simulation results at y=2m in winter are shown in Fig. 7. The parameters can meet the requirements of specifications, and the temperature, relative humidity and airflow velocity are evenly distributed. Based on the distribution characteristics of airflow parameters in winter and summer of 3 cases, case 1 can be determined as a reasonable air supply case for generator layer.
5 Conclusion

Numerical simulation has been conducted for airflow characteristics of three cases in a generator floor. Following conclusions can be drawn:

(1) According to the comparison of results of the characteristics of airflow parameters, case 1 with 30 swirl diffusers can achieve a better jet flow pattern. The air temperature and humidity meet the requirements and are of good uniformity.

(2) The simulation results of winter condition of case 1 shows that the temperature, humidity and air velocity all meet the requirements in the specification. It can be determined that case 1 is a reasonable air scheme for tall space of generator floor.

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