CFD analysis of flow field in aromatics extraction unit

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Abstract. The technology of monitoring and tracing the unorganized emissions of VOCs in petrochemical parks is a research hotspot. The characteristics of the wind field at the monitoring point are the key to traceability. Aiming at the Daqing Refinery aromatics extraction equipment, the CFD method was used to simulate the transient flow in the equipment area under 160 ° and 300 ° atmospheric wind. The results show that the flow direction of the local flow field at different positions is different, and the stability of the flow direction is also inconsistent. The local flow field at the monitoring point is related to both the location and the wind direction. When the natural wind changes, the direction and stability of the flow field also change. The flow stability in the vortex region is poor.

1. Introduction
The petrochemical industrial park has developed rapidly in recent years. While bringing huge economic benefits, the pollution problem is also becoming increasingly serious. Studies have shown that industrial sources are the largest source of Volatile organic compounds (VOCs) contributions[1-2]. VOCs can cause great harm to the atmospheric environment and human health, and have become a hot spot in international research. It helps to generate secondary pollutants, has a very important role in promoting the formation of composite air pollution, and enhances the global greenhouse effect. At the same time, it is toxic and odorous, which may affect the central nervous system and digestive system of the human body and cause harm to human health. If the leakage reaches a certain level, it may lead to production accidents such as combustion and explosion, causing major casualties and economic losses[3].

Emissions of air pollutants from petrochemical companies include organized and unorganized emissions. The monitoring and control measures of organized emissions are relatively complete. In contrast, the monitoring, evaluation and management of unorganized emissions is more difficult[4-5]. According to a study by the US EPA National Executive Investigation Center, the VOCs emissions from equipment leaks account for about 0.01% of crude oil processed at refineries. VOCs emissions caused by equipment leaks far exceed the processes of container storage, sewage treatment, transfer manipulation, and ventilation. The leakage of valves and connections accounts for more than 90% of the total leakage emissions[6]. Therefore, the unorganized emission of storage tanks, equipment and pipelines is the focus of VOCs control.

Distributed monitoring technology installed inside the park is an effective method to monitor the unorganized leakage of VOCs[7]. It can monitor the concentration of VOCs in the park in real time. Once the concentration exceeds the standard, the system will alarm and reverse the source of the leak. And how to lock the leak source based on the monitoring point information is one of the key goals of distributed monitoring. The diffusion path of unorganized leaked VOCs is greatly affected by the local flow field. Because the natural wind is blocked by the devices in the park, the local flow is inconsistent
with the natural incoming flow. Flow may be unobstructed in sparsely-equipped areas, and chaotic in densely-equipped areas. Studying the characteristics of local wind fields in the park is very important for traceability of VOCs.

2. VOCs monitoring system
Figure 1 shows a distributed monitoring network of VOCs in an aromatics extraction unit of Daqing Refinery. The aromatics extraction equipment area includes two platforms, two pump rooms, and ground process units, covering an area of 100 × 60 m². 60 monitoring points were set up to monitor VOCs concentration. A meteorological parameter sensor was placed at a height of 18 m to collect meteorological parameters such as wind speed, wind direction, temperature and humidity. The system will analyze the composition of 7 media of pentane, hexane, heptane, benzene, toluene, xylene and ethylbenzene in each measurement point area in real time. The system will analyze the composition of 7 media of pentane, hexane, heptane, benzene, toluene, xylene and ethylbenzene in each measurement point area in real time.

![Figure 1. Aromatics extraction unit.](image)

3. CFD model
The computational domain is shown in figure 2. Large buildings around the equipment are also modeled to consider their impact on the flow field in the equipment area. Ansys workbench cutcell method is used to mesh the calculation domain. The number of grids is 14 million. The calculation domain is unsteady incompressible flow, the turbulence model is \(k-\varepsilon\), and the SIMPLE algorithm is used for pressure coupling. The surface of the computational domain except the ground is set as a uniform velocity entrance, and the velocity boundary adopts an exponential rate wind profile[8]

\[
u = u_0 \left(\frac{z}{z_0}\right)^{0.22}
\]

where \(u\) is the wind speed at \(z\) height, m/s; \(u_0\) is the natural wind speed at \(z_0\) height, m/s. \(z_0\) (= 18m) is the height at which the meteorological parameter sensor is installed. The power index for urban areas is 0.22.
Figure 2. The computational domain

The atmospheric wind speed at 18 m is 1 m/s. Atmospheric wind directions are 160° and 300°. The flow simulation time is 3600 s and the time step is 0.5 s. Commercial software Fluent was used to simulate the flow. In the calculation, the speed components of 50 outdoor monitoring points are monitored.

4. Results

In order to exclude the influence of the unstable section at the beginning of the simulation, the monitoring data of the first 1000 s was removed. Figure 3 shows the wind direction over time at P1, P3, P4, P25, P32, P34, P38. The wind direction at P1, P3, P25, and P32 is relatively stable under 160-degree atmospheric wind, but the wind direction is not consistent. For example, the wind direction at P3 is 238°, and the wind direction at P32 is maintained at 182°. The wind direction of P4 and P38 is very unstable, and the wind direction of P4 is distributed in the range of 0 ~ 360°. It indicates that the stable natural wind is blocked by various buildings in the equipment area, resulting in a change in flow. The direction and stability of flow in different regions are not consistent. Comparing the local flow of the monitoring points under the two atmospheric winds, it can be found that when the incoming flow direction changes, the direction and stability of the flow will also change. For instance, local flow at point 1 is very stable under 160° atmospheric wind, but becomes unstable at 300°.
Figure 3. Comparison of wind directions at monitoring points under two atmospheric winds

Figure 4 compares the variances of the wind direction signals at monitoring points under two atmospheric winds. Under 160° natural wind, the wind direction at P32 is the most stable, while the wind direction at P4 is the most unstable. The flow stability of monitoring points other than point 4 under 300° natural wind is worse than that of 160° natural wind.

Figure 5 shows the local wind field of P1 under two atmospheric winds. Under the 160° atmospheric wind, P1 is on the windward side, and the air flows along the surface of the component, so the direction...
is very stable. Under the 300 °C atmospheric wind, P1 is located in the tail vortex area of the leeward surface. The flow direction is very unstable. P25 is located in the channel formed by the tank cofferdam and the pump room. Figure 6 (a) shows that the chaotic airflow enters the channel and is rectified and stabilized. However, under 300 °C atmospheric wind (figure 6 (b)), the air flow does not pass through the channel, and the flow field is chaotic. Figures 7 and 8 show that the P34 and P38 are in the vortex region under both incoming flows, so their flow field stability is relatively poor.
5. Conclusion

The CFD method was used to simulate the wind field in the area of aromatics extraction equipment, and the flow information at each monitoring point under 160° and 300° atmospheric wind was obtained. It can be found:

1. The flow direction of the local flow field at different positions is different, and the stability of the flow direction is also inconsistent;

2. The local flow field at the monitoring point is related to both the location and the wind direction. When the natural wind changes, the direction and stability of the flow field also change.

3. The flow stability in the vortex region is poor.

Acknowledgments

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