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Influence of the Haizhou Open Pit Coal Mine on the atmospheric flow over Fuxin, China

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Abstract: The influence of the Haizhou Open Pit Mine on the atmospheric flow in nearby Fuxin City in China was analyzed with the aid of the steady-state Navier-Stokes equations. The finite element method was used to obtain numerical solutions to these equations. The results showed that the Haizhou Open Pit Coal Mine contributes to the turbulent flow in the Fuxin City and its surroundings. However, when compared with the climatic effects, the open pit mine has a relatively small impact on the atmospheric flow over Fuxin.

Keywords: numerical simulation; turbulence; finite element method; open pit coal mine

Introduction

Fuxin is a city in Liaoning Province of northeast China, with a large open pit coal mine located nearby. Strong winds blow over the city almost continuously. On those occasions when the winds are gentle the air over the city is stagnant. At such times atmospheric pollutants usually accumulate in the city, causing serious air pollution problems.

The Haizhou Open Pit Coal Mine, the largest such mine in China, is located to the south of Fuxin. The pit is a huge excavation whose dimensions are four kilometers in length, two kilometers in width, and about 300 m in depth. Researchers have been uncertain about the degree to which the Haizhou Pit influences the atmospheric flow over Fuxin and its surroundings. If the mechanisms influencing the atmospheric flow over the Haizhou Pit were understood, analysts would have a solid theory for understanding the way in which atmospheric pollutants are diffused in the region. This theory would also assist planners in making decisions concerning the location of factories and other types of civic facilities in the area surrounding the Haizhou Pit.

To study this problem we employed atmospheric boundary layer theory. The Navier-Stokes equations were used to model fluid flows. We solved the Navier-Stokes equations with the aid of numerical simulation methods. A few other researchers have reported on studies that are related to our work. Mountain and valley winds in Japan were studied by Mannouji(Mannouji, 1982), and San and Reiter (San, 1983) examined atmospheric flows in a large-scale mountain valley with the aid of numerical models. Granger and Meroney (Grainger, 1993) used a physical model to study the dispersion in an open pit coal mine under the condition of a stably stratified flow. Zhu(Zhu, 1997) had studied fluid flow past concave topographies, but his work was largely theoretical and did not address practical applications analogous to those in this paper.

1 Numerical simulation and results

In our study of the mechanisms influencing the atmospheric flow over Fuxin, the Navier-Stokes equations that model fluid flows were used. It is not possible to obtain analytical solutions to these partial differential equations. Therefore it is necessary to employ numerical methods. The finite element method is appropriate and effective for this purpose and is suited to problems with complicated boundaries in multi-connected regions. It also has the ability to remove difficulties of transformation within regions and the definition of the grid is easily formulated.

1.1 Mathematical model

We consider the atmosphere as a steady incompressible viscous fluid, the flow of which can be described with the Navier-Stokes equations. Atmospheric flow differs from general fluid flow in that the scale of eddies is restricted when fluid flows in channels, and the upper boundary of the atmospheric flow does not exist(Chen, 1998; Hood, 1974; Williams, 1980). The Reynolds number in the solution domain is larger than 3000 (the critical number) so the atmospheric flow is a turbulent flow obeying the following equations(Shi, 1994).

Continuity Equation

$$\frac{\partial \langle U_i \rangle}{\partial x_i} = 0. \tag{1}$$

Reynolds Equations

$$\frac{\partial \langle U_i \rangle}{\partial x_j} \langle U_j \rangle = f_i - \frac{1}{\rho}\frac{\partial \langle P \rangle}{\partial x_i} + \upsilon \frac{\partial^2 \langle U_i \rangle}{\partial x_j \partial x_j} - \frac{\partial}{\partial x_i}\langle u'_i u'_j \rangle, \tag{2}$$

$k-\varepsilon$ model

$$\langle U_j \rangle \frac{\partial k}{\partial x_j} = P_k + \frac{\partial}{\partial x_j}\left[\left(\upsilon + C_k \frac{k^2}{\varepsilon}\right)\frac{\partial k}{\partial x_j}\right] - \varepsilon, \tag{3}$$

$$\langle U_j \rangle \frac{\partial \varepsilon}{\partial x_j} = C_{\varepsilon 1}\frac{\varepsilon}{k}P_k + \frac{\partial}{\partial x_j}\left[\left(\upsilon + \frac{C_\varepsilon k^2}{\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_j}\right] - \frac{C_{\varepsilon 2}\varepsilon^2}{k}, \tag{4}$$

$$-\langle u'_i u'_j \rangle = \nu_t\left(\frac{\partial \langle U_i \rangle}{\partial x_j} + \frac{\partial \langle U_j \rangle}{\partial x_i}\right) - \frac{2}{3}\delta_{ij}k. \tag{5}$$

Where, $P_k = -\langle u'_i u'_j \rangle \frac{\partial \langle U_i \rangle}{\partial x_j}$, $\nu_t = C_\mu \frac{k^2}{\varepsilon}$, k is the turbulent kinetic energy, ε is the dissipation rate of turbulent kinetic energy, $R_{ij} = -\langle u'_i u'_j \rangle$ is Reynolds number, x_i is the curvilinear coordinates, $\langle U_i \rangle$ is the mean velocity. Standard values are assigned to the constants appearing in the turbulence model, namely, $C_\mu = 0.09$, $\sigma_\varepsilon = 1.3$, $C_{\varepsilon 1} = 1.45$, $C_{\varepsilon 2} = 1.92$, $C_\varepsilon = 0.07$, $C_k = 0.09$(Chen, 1984).

From the above equations we can get the finite element equations.

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1.2 Boundary conditions and meshing

Because the width of the pit is small compared to the length, we consider a two-dimensional flow across the pit.

Based on meteorological data, the northwest wind is the cardinal wind in Fuxin. Furthermore, the Haizhou Open Pit Mine is located to the southeast of Fuxin, therefore southwest winds and northeast winds flowing over the pit have little impact on the city. The velocity boundary conditions shown in Fig. 1 indicate the condition that the north wind flows across the pit. The influence of the open pit coal mine on the atmospheric flow far above the ground is small and can be neglected. We suppose that the velocity of the air on the upper and left-hand and right-hand sides is equal to the velocity of the wind, which is 1 m/s in the X-direction. There should be a wind velocity gradient near the ground because the air is considered as a viscous fluid. Hence the velocity of the atmospheric flow there is assumed to be zero.

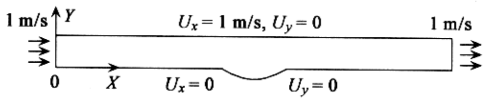

Fig. 1 Simulation domain and boundary conditions

What concerns human beings most is the atmospheric flow near the ground, therefore the grid density near the ground is finer than that far above the ground. The mesh used is shown in Fig. 2.

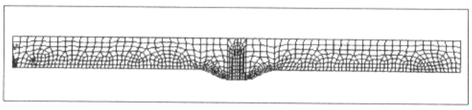

Fig. 2 Mesh

1.3 Results and discussion

We compared the atmospheric flow of the south side to that of the north side in order to investigate the influence of the Haizhou Open Pit Mine on the atmospheric flow in Fuxin. In a general way, the heating power action and the dynamic action determine the turbulence in the atmosphere. When the rate of temperature drop is high, the heating power action is the dominant effect. On the other hand, the dynamic action is dominant when the rate of temperature drop is low (Liu, 1998). The simulation described below was done with the condition that the wind flows across the open pit mine and the heating power action is neglected.

Fig. 3 and Fig. 4 show the pressure contours when the wind flows across the pit. As can be seen from these figures, the pit greatly impacts the atmospheric flow in nearby area. As shown in Fig. 5, the pressure contours slope gradually upward from the left side to the right side, therefore we can conclude that the pit has a greater impact on the south side than on the north side. Furthermore, in Fig. 5 this difference is even more apparent.

The boundary conditions for the first solution (assuming the presence of the pit) are the same as those for the second solution (assuming the pit is absent). In Fig. 6, a comparison of the velocity vectors clearly indicates that the pit contributes to the turbulent flow.

In order to analyze the main fact that influences the atmospheric flow of Fuxin, we simulated the atmospheric flow of a strong wind through the city without Open Pit Coal Mine.

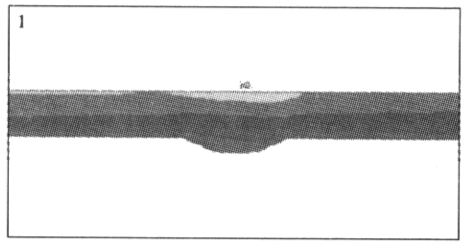

Fig. 3 Pressure contours

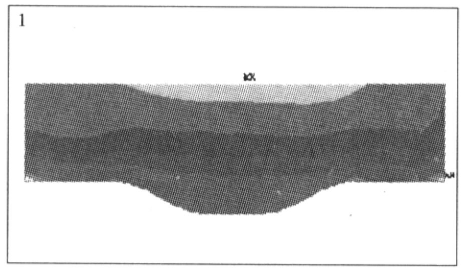

Fig. 4 Pressure contours around the pit

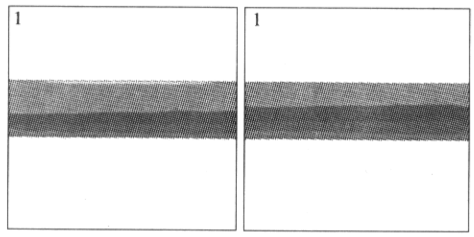

Fig. 5 Comparison of pressure contour to north and south sides

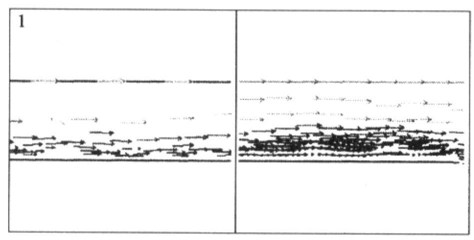

Fig. 6 Comparison of velocity vectors in the same area when the pit exists and not

The dimensions of the simulation domain are forty kilometers in length, one kilometer in height. The city is always disturbed by winds with a speed of about 10 m/s, so we suppose that the velocity of the air on the upper and left-hand and right-hand sides is equal to the velocity of the wind, which is 10 m/s in the X-direction. The velocity of the atmospheric flow near the ground is assumed to be zero. The velocity vectors of natural wind with a speed of 10 m/s without the Open Pit Coal Mine is shown in Fig. 7. The atmospheric flow is more turbulent in Fig. 7 than that in Fig. 6.

In order to further investigate in what a degree the Open Pit Coal Mine influences the atmospheric flow of Fuxin, we employed a variable named £ that indicates the human sense of disturbing winds. £ is determined in the following equation.

$$£ = \langle u'_i u'_j \rangle^{1/2}. \quad (6)$$

We set a point 5 meters above the ground in the center

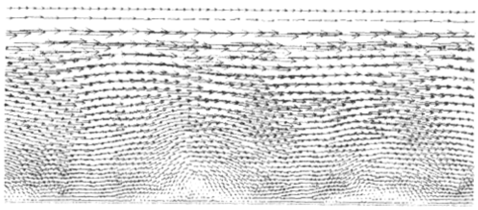

Fig.7 Velocity vectors of natural wind (10m/s)

of the city and respectively calculated the £ of this point in three conditions. In the first condition that the wind speed is 1 m/s and there exists the Open Pit Coal Mine the £ is equal to 0.32. In the second condition that the wind speed is 1 m/s and there does not exist the Open Pit Coal Mine the £ is equal to 0.13. In the third condition that the wind speed is 10 m/s and there does not exist the Open Pit Coal Mine the £ is equal to 0.85. As can be seen from the above results, the pit is not the dominant cause because the pit plays a smaller role in abnormal atmospheric flow over Fuxin than eccentric climatic factors do. Fuxin lies in the North Temperate Zone where the winds are determined mainly by climatic factors (strong winds caused by atmospheric pressure). A continental climate has an impact upon Fuxin when northwest winds prevail. During such times the atmospheric pressure gradient is high, which accounts for strong and abnormal winds in the city.

A comparison of velocity vectors, as shown in Fig.8 and 9, indicates that the pit has a greater influence on the leeward side than on the windward side. This reveals that the pit is a factor that results in turbulent flows. In addition, solar energy assimilated by the air can cause a change in the air density. A redistribution of density will give rise to local atmospheric circulation, which can influence the general atmospheric flow.

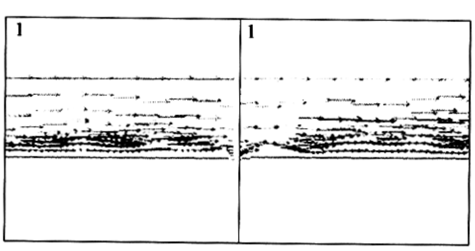

Fig.8 Comparison of velocity vectors in the spots 3 km from the north and south sides

2 Conclusions

In this paper we have shown the results from a simulation of the atmospheric flow over the city of Fuxin in China. As can be seen from these results, the Haizhou Open Pit Mine influences the atmospheric flow over Fuxin because the pit has the effect of strengthening abnormal flows over the city. The dominant influence on atmospheric flow in Fuxin is derived from the eccentric climate. Because the Open Pit Coal Mine has a greater influence on the leeward side than on the windward side, south winds have a greater influence on the city than winds from other directions. When winds are strong and the atmospheric flow is abnormal, the pit has a negative influence on the atmospheric flow. On the other hand, the pit has a positive influence derived from its ability to diffuse air pollutants.

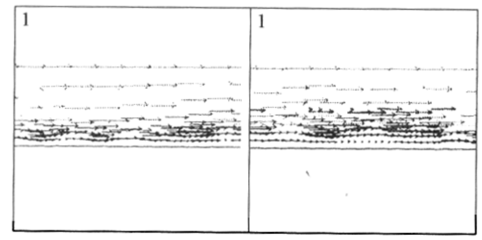

Fig.9 Comparison of velocity vectors in the spots 5 km from the north and south sides

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