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Simulation Analysis of Tunnel Diesel Oil Explosion Based on FLACS

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Abstract: The tunnel explosion model was established by using Gexcon Flacs to simulate the explosion of 3m^3 diesel oil in a tunnel. The temperature, O_2, fuel concentration and pressure field distribution during the explosion in the tunnel were analysed. The simulation results show that the temperature of the initial explosion point varies most dramatically during the explosion, and the maximum temperature can reach 1093℃. The pressure pulse can reach 25Pa*s. When t is equal to 1.135s, the diesel oil doesn't burn completely. In the section Y=7.4m along the length direction of the tunnel, the area 1.5m above the ground is the most dangerous area.

1. Introduction
The number of tunnels is increasing rapidly with the development of economy. Once the dangerous goods explode in the tunnel, the huge pressure wave and high temperature generated by the explosion will affect the safety of personnel, the reliability of the tunnel and subsequent rescue.

Chen Changkun et al. [1]simulated the explosion of hydrogen and propane in highway tunnels, and analyzed the reaction speed and pressure field, and the influence of tanker number and ignition position on the distribution of pressure were analyzed[2]. Gao Xuanneng et al. [3-5] established the dynamic response analysis model of the tunnel, and analyzed the pressure field distribution, the influence of ignition position and the empirical formula for calculating the peak attenuation of overpressure. Li Zhipeng et al. [6-7] revised the key parameters of RHT model, and established the fluid-solid coupling numerical model. Furthermore, the characteristics of tunnel shock wave and the distribution of tunnel damage were studied. V.R. Feldgun et al. [8] established a complex calculation method for analyzing the explosion of underground tunnels, which took into account the shear elastic-plastic properties of soil. Seyedan M J et al. [9] focused on the deflection change when the blast wave acted on the tunnel. Feldgun et al. [10] used finite difference method to study the dynamic response of explosive load in tunnel and surrounding soil.

In summary, the research on the explosion in highway tunnels mostly focused on gas and hydrogen, while the study on the explosion of diesel oil is rare. The objective of this article is to simulate the explosion of 3m^3 diesel oil in a tunnel by Gexcon Flacs. Then, the temperature, O_2, fuel concentration and pressure field distribution during the explosion in tunnel were analyzed.

2. Model of tunnel explosion
The tunnel model was built according to a single-line highway tunnel. The section of the tunnel was simplified to a semicircle with a radius of 5.5 m and a rectangle with 11 m×5 m. In this paper, the width direction of the tunnel was the X direction, the length direction was the Y direction, and the

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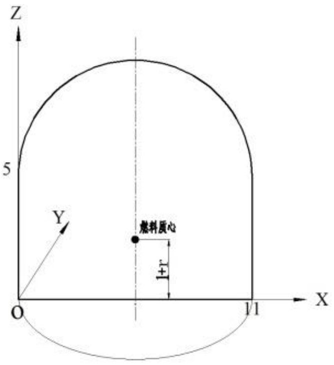
height direction was the Z direction. The diesel oil transporter was located in the middle of the X direction. The gravity center of the diesel was (5.5m, 1+r) in the XZ section (r is the radius of the tank), as shown in Figure 1.



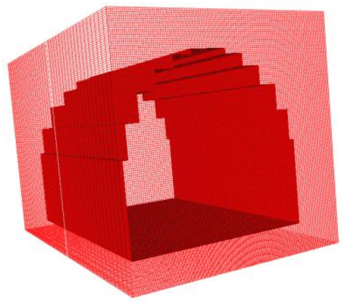


Figure 1. Tunnel section physical model

Figure 2. Tunnel explosion simulation geometry model

During the explosion process, the state parameters still followed the laws of mass conservation, momentum conservation and energy conservation. The flow field was a three-dimensional transient turbulent flow field, and the governing equation was Equation 1.

$$\frac{\partial}{\partial t}(\rho\varphi)+div(\rho u\varphi-\Gamma grad\varphi)=S_{\varphi} \quad (1)$$

Where: ρ is the mean value of fluid density, kg/m3; φ is the mean value of the general variable; u is the mean value of velocity, m/s; Γ is the turbulent transport coefficient of φ; S_{φ} is source item for different φ.

The equation of state for the fuel used the equation, as in Equation 2.

$$p_z=A\left(1-\frac{\omega}{R_1V}\right)^{e^{-R_1V}}+B\left(1-\frac{\omega}{R_2V}\right)^{e^{-R_2V}}+\frac{\omega E_2}{V} \quad (2)$$

Where: p_z is the explosion pressure; V is the relative volume of the explosive product; E_z is the specific energy of the detonation product; A, B, R_1, R_2, ω are selected parameters.

For the rapid and intense chemical reaction such as gas combustion or explosion, the mass fraction of fuel during the explosion can be expressed as Equation 3.

$$\frac{\partial}{\partial t}(\rho m_{fu})+\frac{\partial}{\partial x_j}(\rho u_j m_{fu})=\frac{\partial}{\partial x_j}\left(\Gamma_{fu}\frac{\partial m_{fu}}{\partial x_j}\right)+R_{fu} \quad (3)$$

Where: u_j is the velocity in the j direction, m/s; x_j is the flow direction of the j axis; Γ_{fu} is the turbulent dissipation coefficient; m_{fu} is the mass fraction of the fuel; R_{fu} is the gas volume burning rate, m^3/s.

2.1 Geometry model of tunnel explosion

The above-mentioned simulated tunnel was simplified into a superposition of many rectangular cross-sections, so the upper was similar to an arc top. In order to make the calculation result more accurate, the calculation volume was set to 12m×680m×11m, which was larger than the tunnel volume, and the tunnel geometric model was meshed, as shown in Figure 2.

2.2 Definition of tunnel explosion

(1) Monitor points

In order to more monitor the temperature, O_2, fuel concentration and pressure field distribution intuitively, six monitor points were set. Their positions were shown in Figure 3. What's more, point1, 2 and 6 were located near the wall of the tunnel, which were to monitor the influence of explosion on the tunnel wall. The point 3、4、5 were used to monitor the influence of explosion on vehicles and personnel.

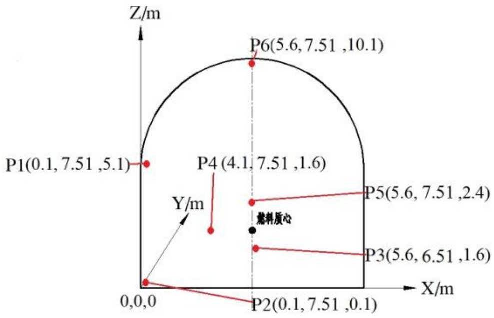


Figure 3. Monitor point distribution

(2) Output parameters

It was necessary to set the 2D and 3D output parameters to analyze the distribution of temperature, O_2, and so on. The selected output parameters were shown in Table 1.

Table.1 Output parameters of 2D and 3D

2D/3D Output parameters	Units	Description
T	K	Temperature
OX	-	Oxygen mass fraction
FUEL	-	Fuel mass fraction
P	barg	Pressure
PIMP	Pa*s	Pressure pulse
PROD	-	Fuel product
RFU	Kg/（m^3*s）	Burning rate

(3) Boundary condition

Before the explosion in the tunnel, the wind power at the tunnel entrance was level 3, along the positive direction of the Y-axis. The inside temperature was 20°C. The atmospheric pressure was 10^5Pa, and the gravity acceleration was 9.8m/s^2.

(4) Ignition point

The gravity center of the diesel was located at (5.5m, 7.5m, 1.5m) and the volume was 3m^3. The starting ignition point was located near the gravity center, which was located at (5.6 m, 7.6 m, 1.6 m). The explosion started at the time of 0s.

3. Analysis of explosion results

The distribution of oxygen mass fraction, fuel mass fraction, fuel mass fraction, pressure, pressure pulse, fuel product fraction, and burn rate at the Y=7.4 m and t=1.135s were shown in Figure 4. The diesel was not completely burned t=1.135s, and it continued to explode. Most of the remaining diesel was located below the initial explosion location as the density of diesel was greater than the air. The oxygen content around the initial explosion location was the least as the reaction consumed oxygen. The pressure at the point near the initial explosion location was the largest, indicating that these area were the most dangerous. The pressure pulse was the largest at the initial explosion position. The fuel reaction rate was the highest in the area below the initial explosion location because the diesel move down during the explosion. What’s more, the maximum temperature could reach to 2200K.

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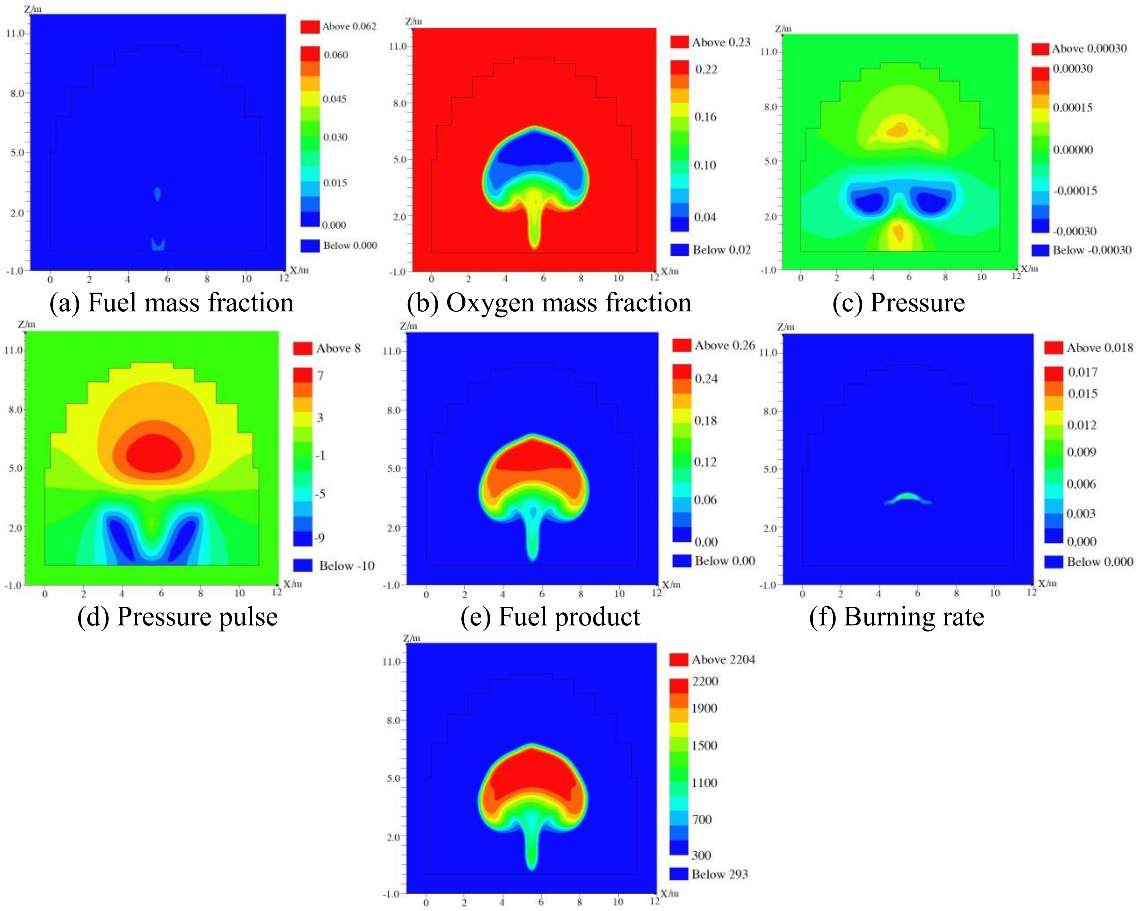


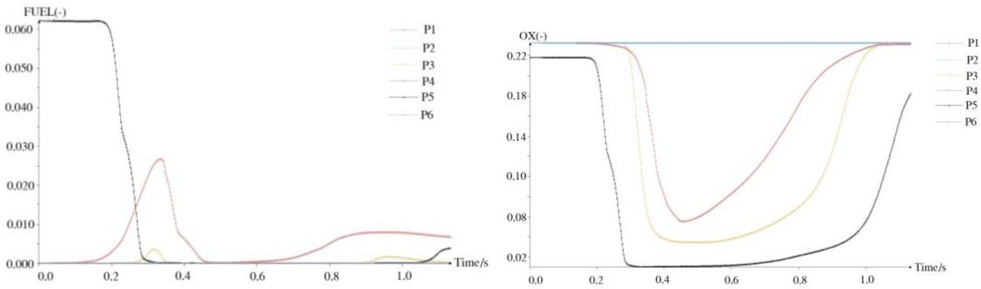
(a) Fuel mass fraction (b) Oxygen mass fraction (c) Pressure

(d) Pressure pulse (e) Fuel product (f) Burning rate

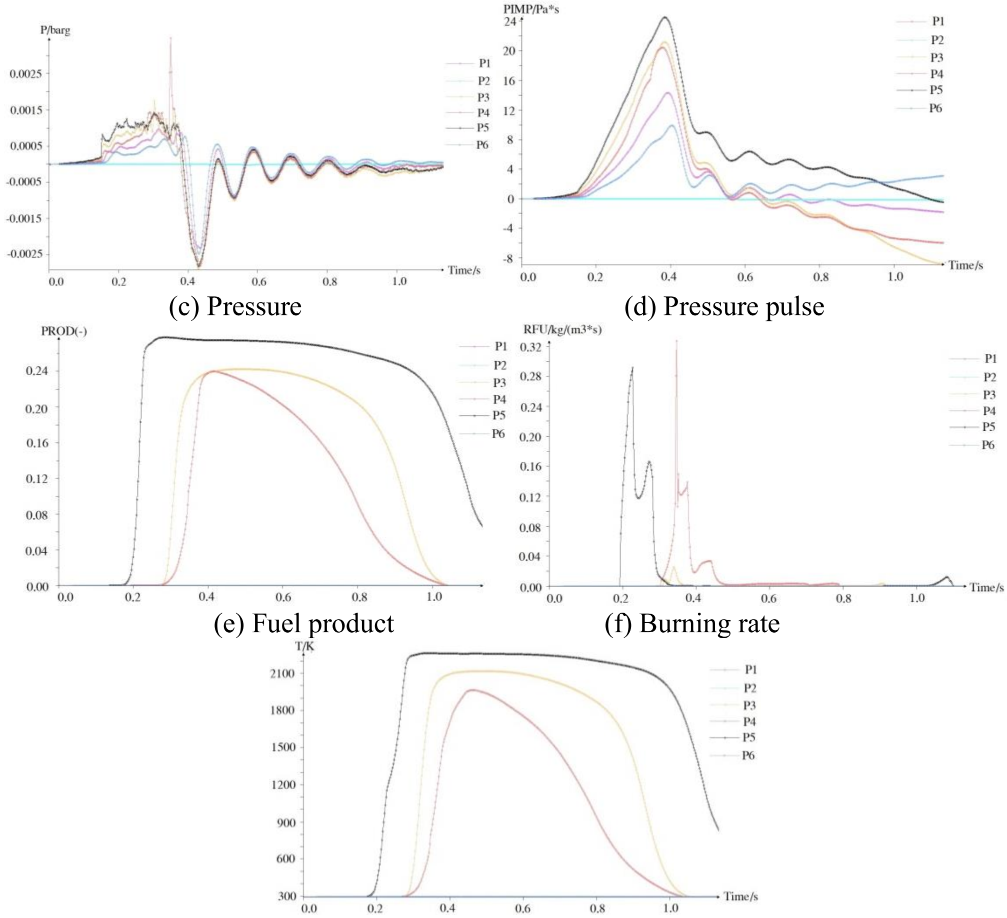
(g) Temperature

Figure 4. Parameter distribution

The variation of the six monitor points for the temperature, oxygen mass fraction and so on were shown in Figure 5. It can be seen that the oxygen content at the monitoring point 6 was almost constant, which was effected by the explosion least. While the oxygen content at the point 5 fluctuated so greatly that the oxygen content was almost zero in the period of 0.25-0.6 s. Furthermore, the fluctuation of the pressure was severe in the period of 0.15-0.4 s, and then it leveled off. Finally, the temperature of monitor point 1, 3 and 5 changed greatly while the other monitor points changed very little.



(a) Fuel mass fraction (b) Oxygen mass fraction



(c) Pressure (d) Pressure pulse

(e) Fuel product (f) Burning rate

(g) Temperature

Figure 5. Parameter variation

4. Conclusion

A simulation model for $3m^3$ diesel oil explosion in a tunnel was built by Gexcon Flacs. The temperature, O_2, fuel concentration and pressure field distribution during the explosion in the tunnel were analyzed. When t is equal to 1.135s, the oxygen content in the initial explosion position was the least. The maximum temperature could reach to 2200K. The oxygen content above the tunnel was affected least. The oxygen content at the point 5 was fluctuated greatly. The temperature at the monitoring points 1, 3 and 5 changed greatly, while the other monitor points changed very little. What's more, the pressure variation of points 1, 3, 4, 5, were very intense, and they had basically stabilized at t=1.135s. The method can reflected the evolution of diesel soil explosion in a tunnel, and provided an effective research method for understanding and studying the explosion of combustibles in tunnels.

Acknowledgments

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