Numerical Computation of Forest Fires

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ABSTRACT: In forest fires, it is often encountered that fire spread characteristics on adverse wind side of tree could be maintained and the damage of tree on adverse wind side is more serious than on towards wind side. The burning process of forest fires are studied by formulating and solving. The computational results are reasonable and promising.

Key Words: Forest fire, Fire spread, Numerical computation

1 INTRODUCTION

In forest fires, it is often encountered that fire spread characteristics on adverse wind side of tree could be maintained, for example, flame could reach at certain height on the side so that crown fire occur or flame stay at certain position on the side and don't continue to burn upward, and the damage of tree on adverse wind side is more serious than on towards wind side. The paper is to study the typical characteristics above by the methods of the numerical computation.

The fluid flow, heat and mass transfer, chemical reaction and their interaction in the burning process of forest fires are studied by formulating and solving a set of governing equations.

In order to compare with experiments, the problem is considered that there is a squared bluff body in fuel bed and research domain is selected according to wind tunnel experiments[1], which is sketched in Figure 1. Considering the simplification of the mathematical treatment of the problem, the value of the speed of the flame spread on fuel bed is directly given according to the experimental results, flame is treated as high temperature gas, gas is considered as one-component, the flow and combustion are turbulent, the gravity is considered. Therefore the governing equations of continuity, momentum and energy are constructed and then solved together with the buoyancy modified k- ε turbulence model[2].

2 NUMERICAL METHOD

The governing equations can be written in general form as

$$\frac{\partial}{\partial x_j}(\rho u_j \Phi) = \frac{\partial}{\partial x_j}\left(\Gamma_\Phi \frac{\partial \Phi}{\partial x_j}\right) + S_\Phi$$

Where Φ stands for general variable, u_j is the component of the velocity, Γ_Φ and S_Φ are the exchange coefficient and the source term of the general variable Φ. Table 1 shows the meaning of them in the general equations.

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*The project was supported by NSFC

Table 1

Meanings of Φ, Γ_Φ and S_Φ in the General Equations

Equation	Φ	Γ_Φ	S_Φ
Continuity	1	0	0
x-Momentum	u	μ	$-\frac{\partial p}{\partial y}+\frac{\partial}{\partial x}\left(\mu\frac{\partial u}{\partial x}\right)+\frac{\partial}{\partial y}\left(\mu\frac{\partial v}{\partial x}\right)+\frac{\partial}{\partial z}\left(\mu\frac{\partial w}{\partial x}\right)$
y-Momentum	v	μ	$-\frac{\partial p}{\partial y}+\frac{\partial}{\partial x}\left(\mu\frac{\partial u}{\partial y}\right)+\frac{\partial}{\partial y}\left(\mu\frac{\partial v}{\partial y}\right)+\frac{\partial}{\partial z}\left(\mu\frac{\partial w}{\partial y}\right)$
z-Momentum	v	μ	$-\frac{\partial p}{\partial y}+\frac{\partial}{\partial x}\left(\mu\frac{\partial u}{\partial z}\right)+\frac{\partial}{\partial y}\left(\mu\frac{\partial v}{\partial z}\right)+\frac{\partial}{\partial z}\left(\mu\frac{\partial w}{\partial z}\right)-\rho g$
Energy	h	μ_t/σ_h	S
k	k	μ_t/σ_k	$G-\rho\varepsilon$
ε	ε	μ_t/σ_ε	$\frac{\varepsilon}{k}(C_1G-C_2\rho\varepsilon)$

$$G=\mu_t\{2[(\frac{\partial u}{\partial x})^2+(\frac{\partial v}{\partial y})^2+(\frac{\partial w}{\partial z})^2]+$$

$$(\frac{\partial u}{\partial y}+\frac{\partial v}{\partial x})^2+(\frac{\partial v}{\partial z}+\frac{\partial w}{\partial y})^2+(\frac{\partial u}{\partial z}+\frac{\partial w}{\partial x})^2+G_B$$

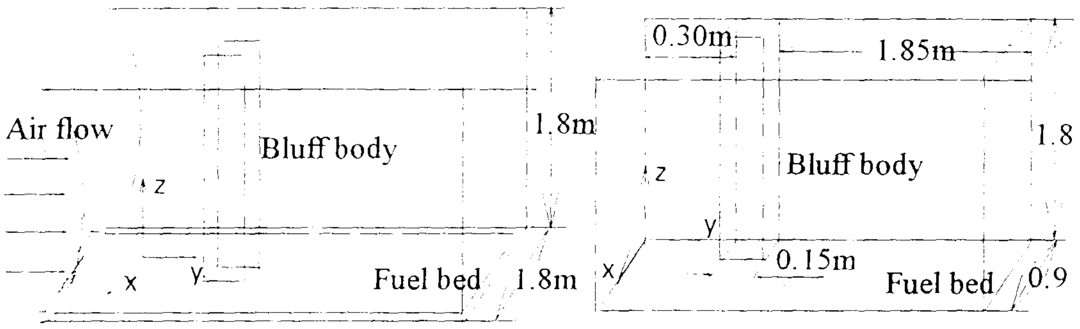
where $G_B=-\beta g\frac{\mu_t}{\sigma_{t,h}}\frac{\partial T}{\partial z}$

$$C_1=\begin{cases} C_3 & \text{horizontal shear flow} \\ C_3(1-C_4\frac{G_B}{G} & \text{vertical shear flow} \end{cases}$$

β is the coefficient of there-expansion, for ideal gas, $\beta = 1/T$. μ is the effective viscosity coefficient made up of laminar and turbulent viscosity coefficients, μ_t is the turbulent viscosity coefficient determined by k- ε model.

3 RESULTS AND DISCUSSION

In order to save computational time and memory, the half of the research domain is selected as the computational domain, which is the symmetrical plane of the bluff body along the flow direction of the wind, which is sketched in Figure 1. To the combustible of the bluff body, the temperature of the ignition T_i is given, if the surface temperature of the body T_p is greater than the ignition temperature T_i, the body surface is considered to begin burning, in the case, let the temperature of the corresponding grid equal to the flame temperature T_f.



(a) A schematic of wind tunnel (b) The Computational domain

Figure 1. Schematic of physial problem

Many results of the burning process of the forest fires have been gained; some typical results are given here. The equations have been discretized in space using QUICK scheme on staggered regular grid[3]. and then solved iteratively with the SIMPLER procedure[4].

At time equaling zero, it is assumed that the fuel bed has began burning and flame has spread to approach to the bluff body, its position is the distance of the two grids to the body(6cm). The speed of the flame spread on fuel bed is 5mm/s. The computational grids are 52 × 40 × 32 non-uniform meshes.

Figure 2 (a) and (b)show respectively the velocity field which corresponds to the x-o-y plane of z equaling 0.6m and the change of u velocity on the back of the body along y coordinate which corresponds to x equaling zero and z equaling 0.3m in the cold condition. In order to easily understand, the velocity field only indicates the direction of the velocity and does not represent its magnitude. From the figure, it can be seen that at the back of the body there is a recurrent zone, u velocity on the back of the body changes from small to large along y coordinate and gradually approaches to the value of the coming flow. The tendency of the velocity change is in consistence with the experimental result.

Figure 3 shows respectively the isotherms' surface at different times after beginning combustion, which correspond to the x-o-y plane of z equaling 0.3m. From the computational results, it can be known that because there is the recurrent zone, hot zone at the back of bluff body is produced and the hot zone is available to ignite the combustible of the body, at the same time, the effects of buoyancy stress flame upward moving on the surface of the body. Finally, it can cause to develop the crown fires. To the surface of upward wind, the grid's temperature above flame have hardly reached the temperature of the ignition T_i, so that the damage of tree on adverse wind side is more serious than on towards wind side.

Furthermore, in the condition of the different speed of the wind the burning process of the bluff body are also computed. In this case, the change of wind speed does not almost affect to the burning at the back of body, but at the surface of upward wind it has a certain effects. At the low speed of wind, it can appear that the flame moves upward on the bidy's surface of the upward wind.

4 CONCLUSIONS

Three-dimension predictions have been performed of the burning process in the forest fires. The computational results obtained are plausible and promising.

The existence of the recurrent zone and the effects of the buoyancy are main reason to produce the crown fires and the serious damage of tree on adverse wind side.

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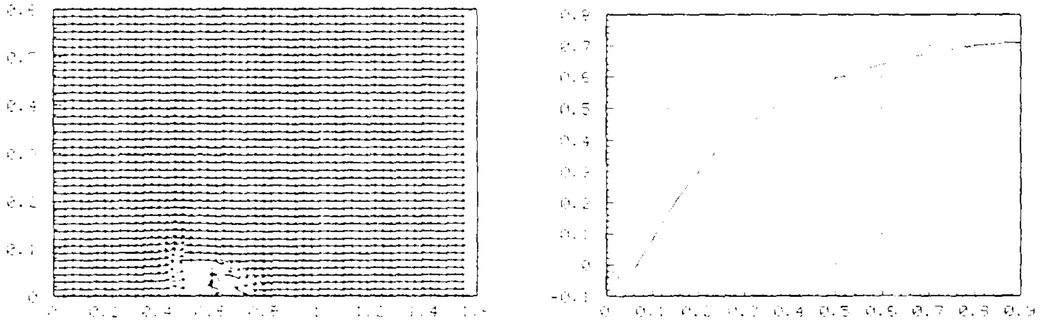
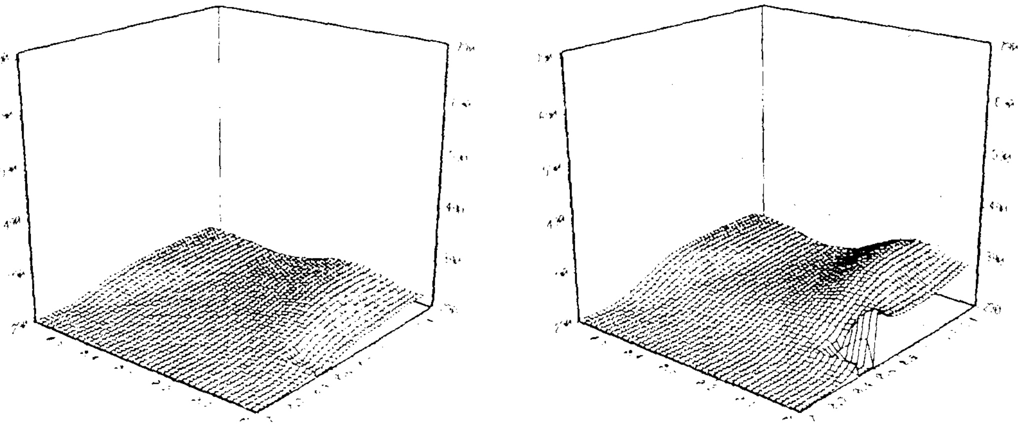


(a) velcoity field (x-o-y, z=0.6 m)

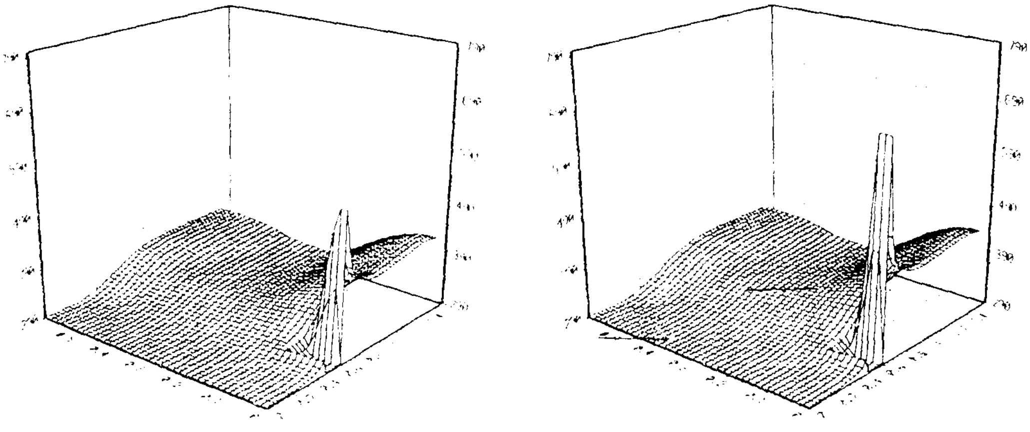
(b) change of u velocity on the back of the body along y (x=0 m,z=0.3 m)

Figure 2. Computational results of $u_\infty = 1.0m/s$ in cold condition



(a) 0.0 second

(b) 48.0 second



(c) 60.0 second

(d) 69.0 second

Figure 3. isotherms' surface at different times after beginning combustion, which correspond to the x-o-y plane of z equaling 0.3m.