Welcome to my talk

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Effect of ultra-fine water mist on methane/air explosions in a closed Vessel

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Outline

1. Background & Introduction
2. Experimental research
3. Numerical research
4. Main conclusions

Gas explosion

High-temperature

Shock wave

Poisonous effect

Gas explosion

High-temperature

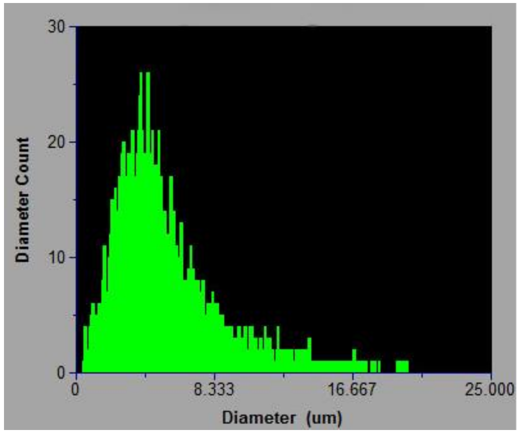
Shock wave

Poisonous effect

How to suppress it efficiently?

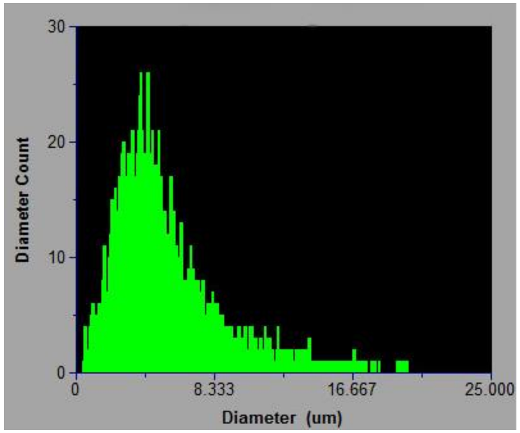
Ultra-fine water mist

Small particle size   Large surface area



Ultra-fine water mist

Small particle size   Large surface area → Easy to evaporate



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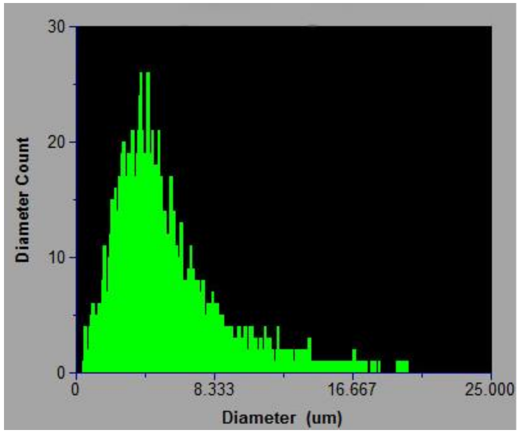

Efficient Heat Absorption

Blocking Heat Radiation

Rapid Suffocation

Ultra-fine water mist

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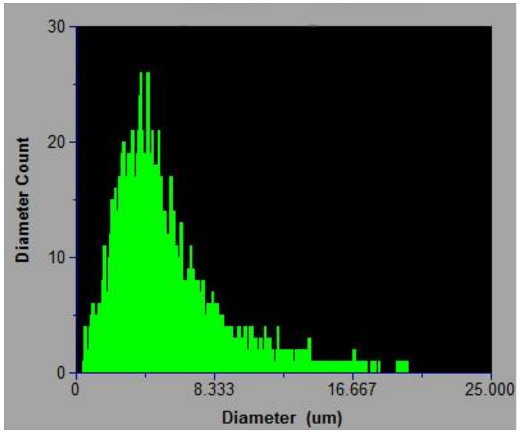


Efficient Heat Absorption

Blocking Heat Radiation

Rapid Suffocation

- **Combustions**
- **Explosions**

- The ultra-fine water mist may have **two opposite** effects on the explosions

Enhancing & Inhibiting

Mainly due to

- The droplet diameter
- The spraying velocity
- The mist concentration

which are related to the atomizing methods.

2 Experimental research

The experimental research of the suppression effect of ultra-fine water mist on methane/air explosions were conducted on the apparatus shown in Figure 1, which mainly consists of:

- a closed vessel
- a gas preparation system
- a ultrasonic atomization system
- an ignition system
- a high speed camera
- a data acquisition & control system

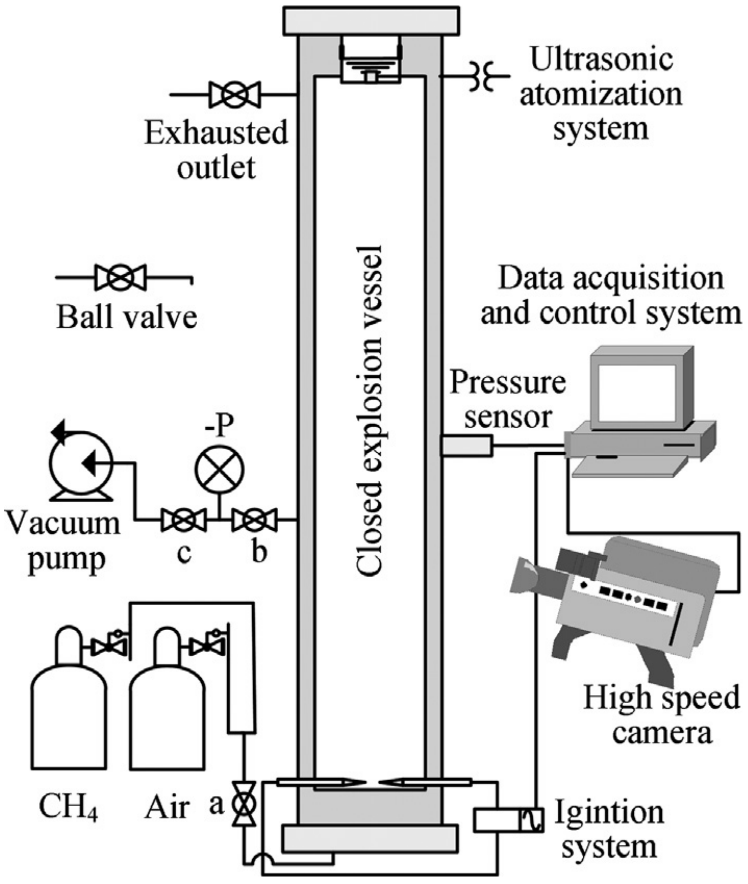


Figure 1 The Experimental Apparatus

2 Experimental research

Figure 2 presents the pressure histories under four different spraying conditions, namely no spraying, spraying 3.75ml, 7.50ml, and 11.25ml. The results show that with the increasing of the mist amount :

- the maximal overpressure decreased and the time for the pressure running up to the maximum was delayed,

which Indicated that

- the increase of the mist amount can promote the suppression effect;

- the decreasing of the maximal overpressure reduced gradually,

which Indicated that

- the suppression effect can't be improved endless by spraying more ultrafine water mist.

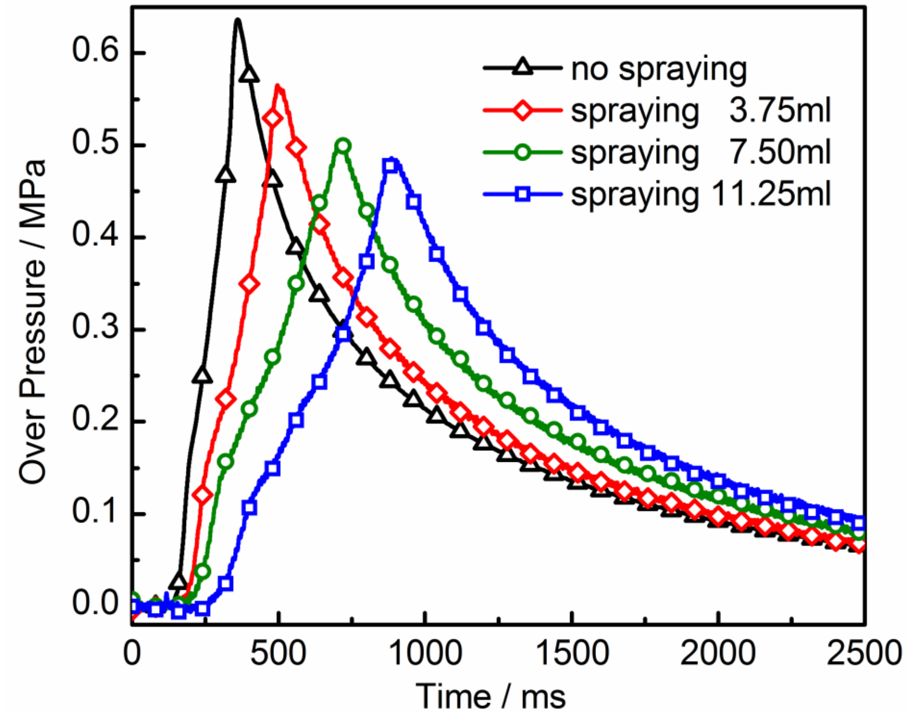


Figure 2 The Pressure histories under different spraying conditions

2 Experimental research

Figure 3 indicates the corresponding relationship between the explosion pressure and the flame pictures of 11% methane explosion.

It can be seen from Figure 3 that,

- **The pressure started to rise dramatically after the flame touched the side wall of the vessel at 55ms;**
- **The curvature of the flame front decreased gradually and the rising rate of the pressure reduced when the flame front flattened out to a plane at 135ms;**
- **The tulip flame formed after that;**
- **The flame front reached to the top end of the vessel at t=375ms and then the flame brightness got to the maximum and the pressure got to the peak value.**

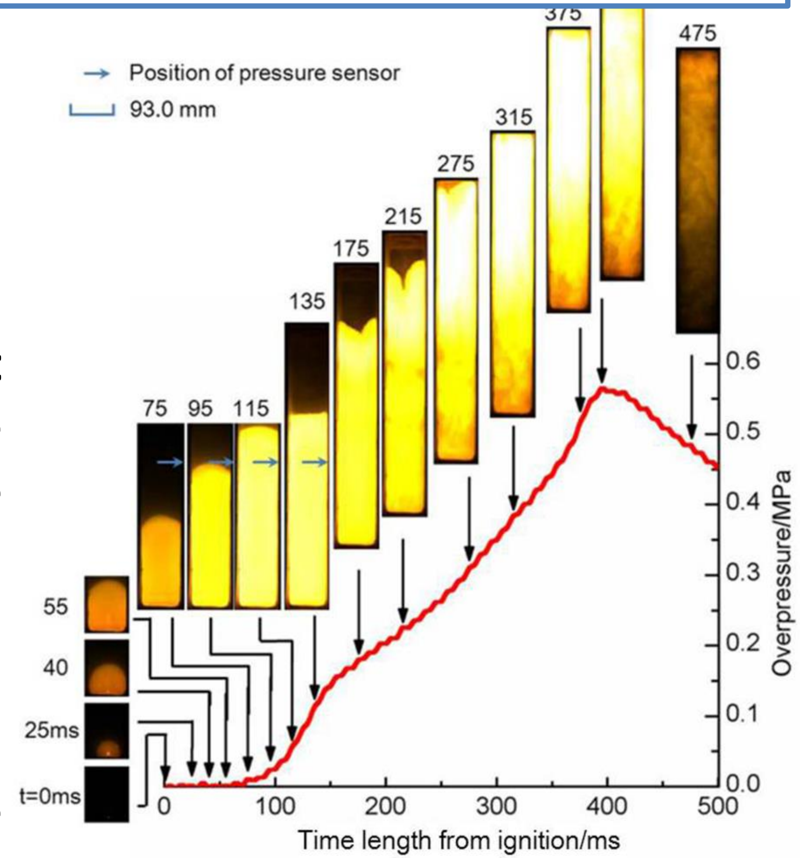


Figure 3 The relationship of explosion overpressure and flame propagation

2 Experimental research

Figure 4 shows the flame propagation process of the explosions under the four spraying conditions. It presents the developing traces of the flame from the ignition point at the bottom of the vessel to the top of the vessel.

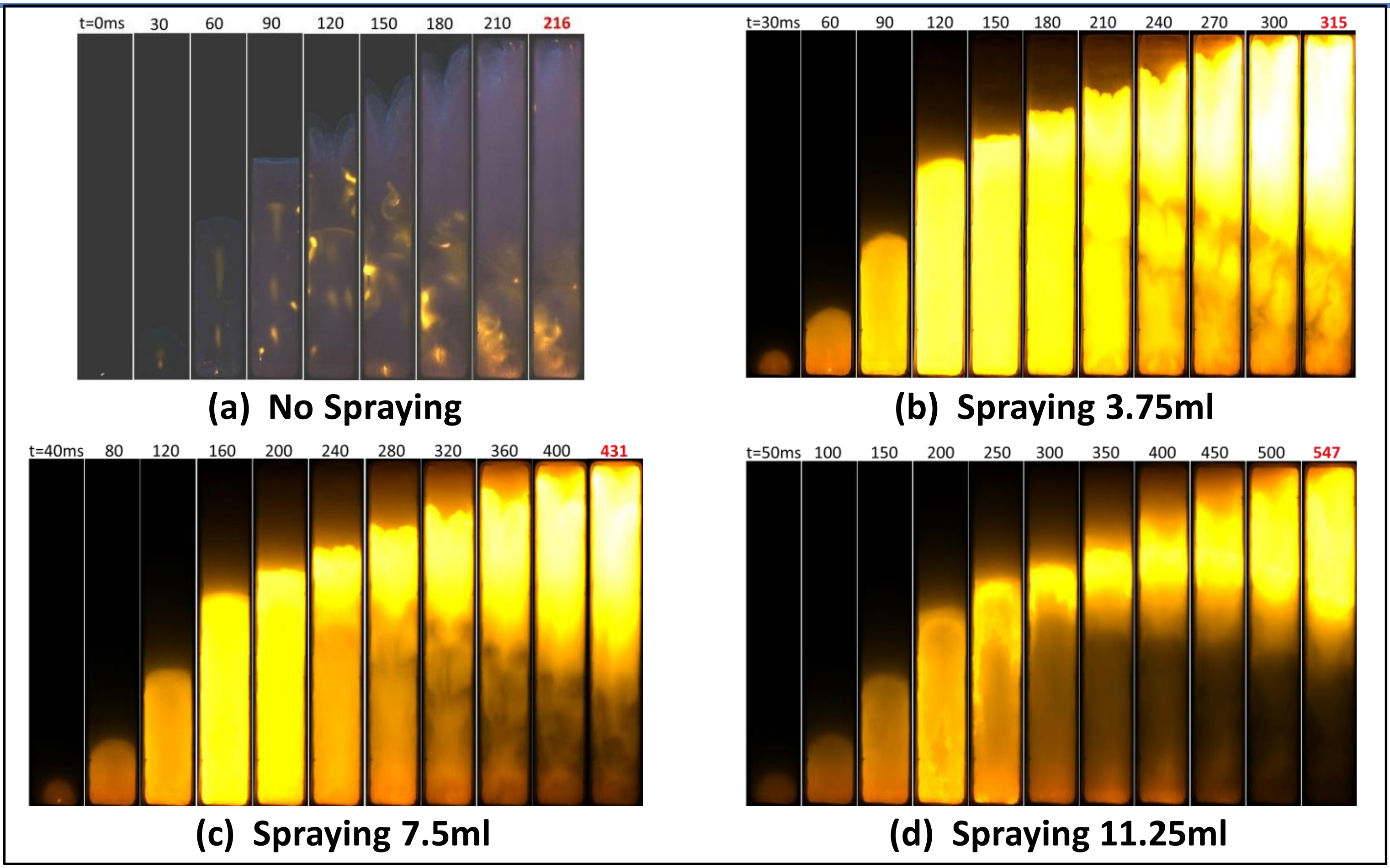
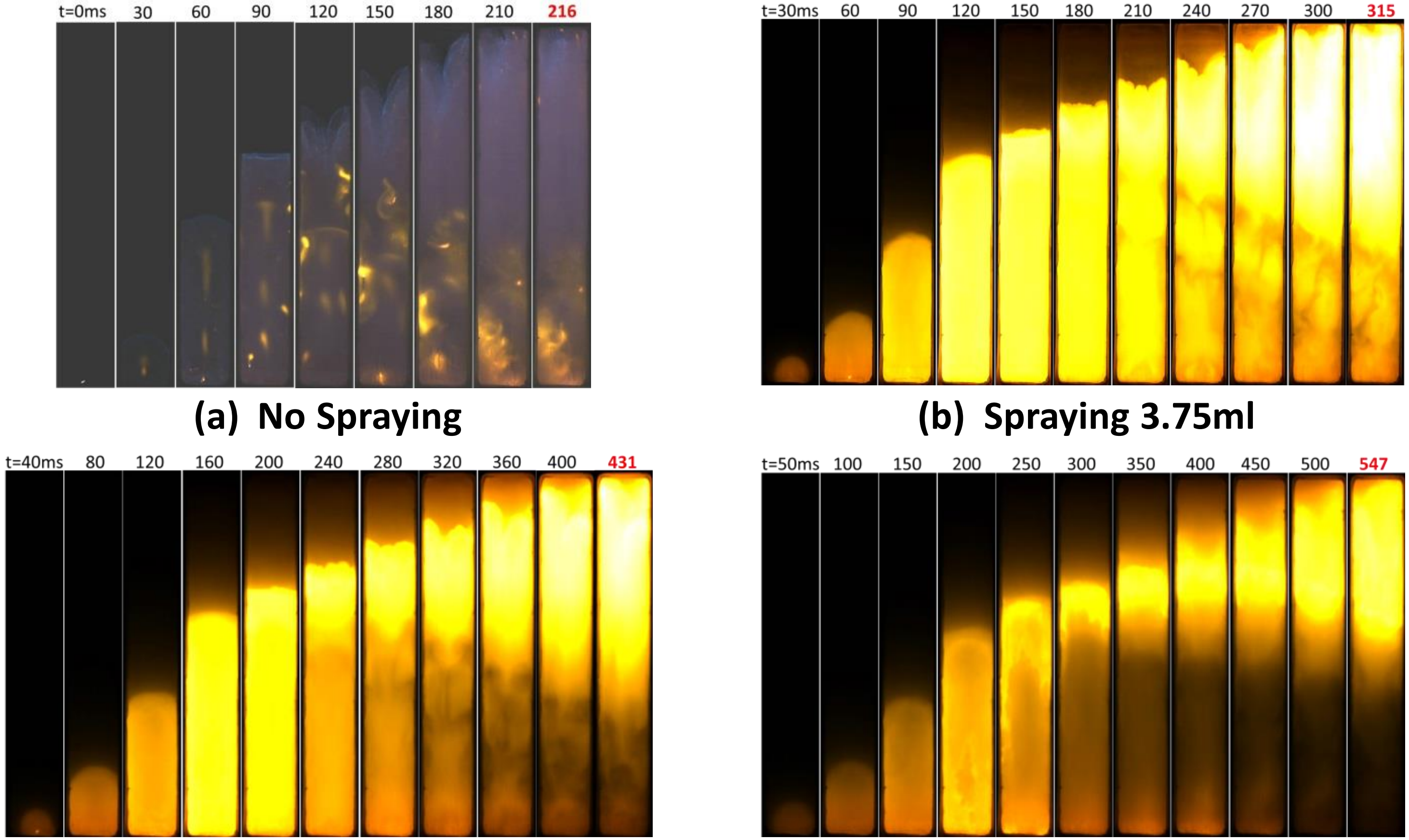


Figure 4 Flame propagating process under different spraying conditions

2 Experimental research

From the pictures we can obtain the following informations:

(i) The time for the flame front reaching the top of the vessel was prolonged for the explosions under no spraying, spraying 3.75ml, 7.5ml and 11.25ml in turn;



(a) No Spraying

(b) Spraying 3.75ml

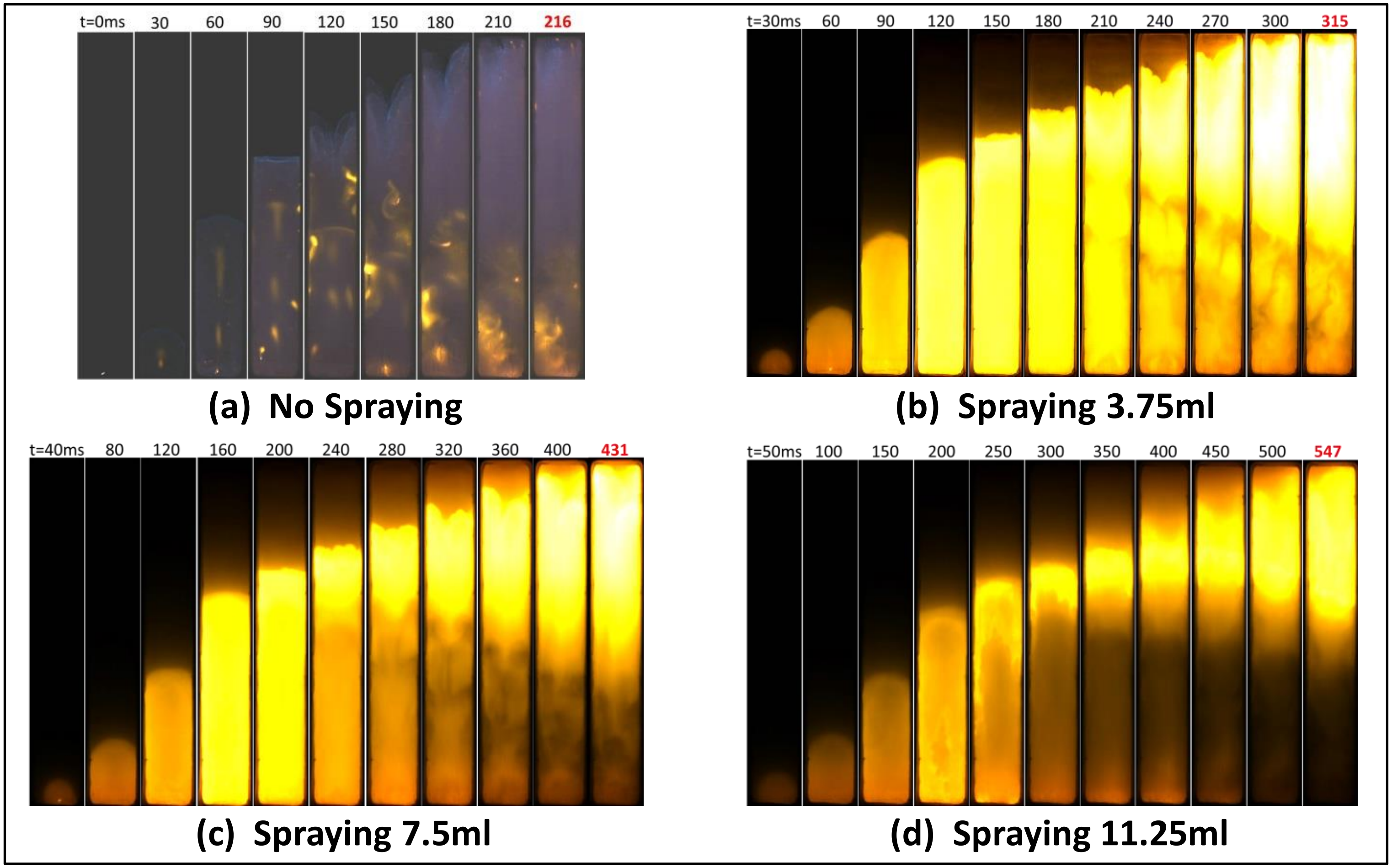
(c) Spraying 7.5ml

(d) Spraying 11.25ml

2 Experimental research

From the pictures we can obtain the following informations:

(ii) The tulip flame became less obvious and almost disappear in the atmosphere of 11.25ml ultrafine water mist.



3 Numerical research

Conditions

- At the initial moment, the fluid was quiescent. The temperature and pressure of the fluid were 300 K and 0.1 MPa, respectively.
- The water mists (10 μm) were released uniformly to every control volume.

Validation

- By comparing the overpressures and flame propagations.

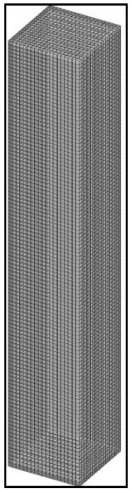


Figure 5 Physical model

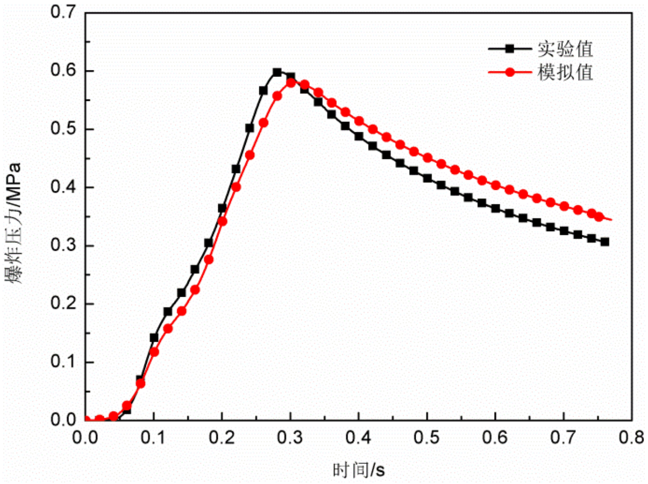


Figure 6 Comparison of overpressures

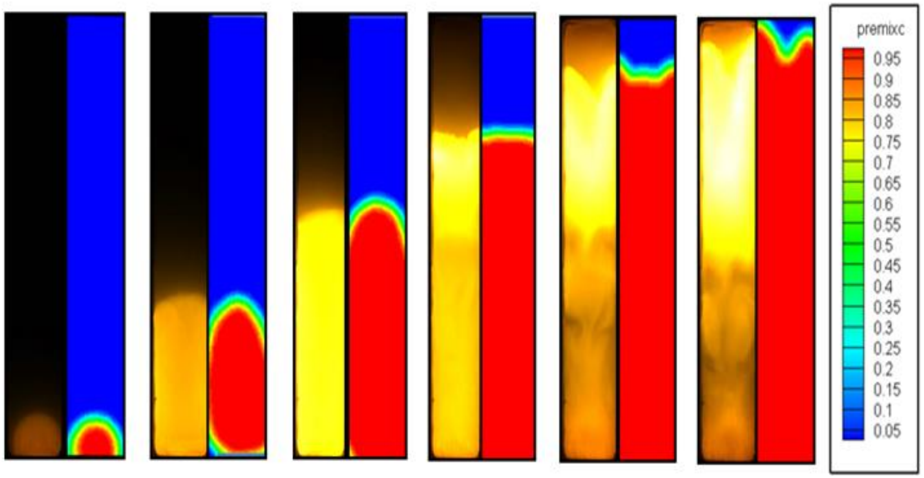


Figure 7 Comparison of flame propagation process

3 Numerical research

Figure8 shows the change of explosion parameter with the reaction process, as it shows, when the explosion reaction occur, the W-M concentration and unburned gas density decrease quickly, but the pressure and temputer increase quickly.

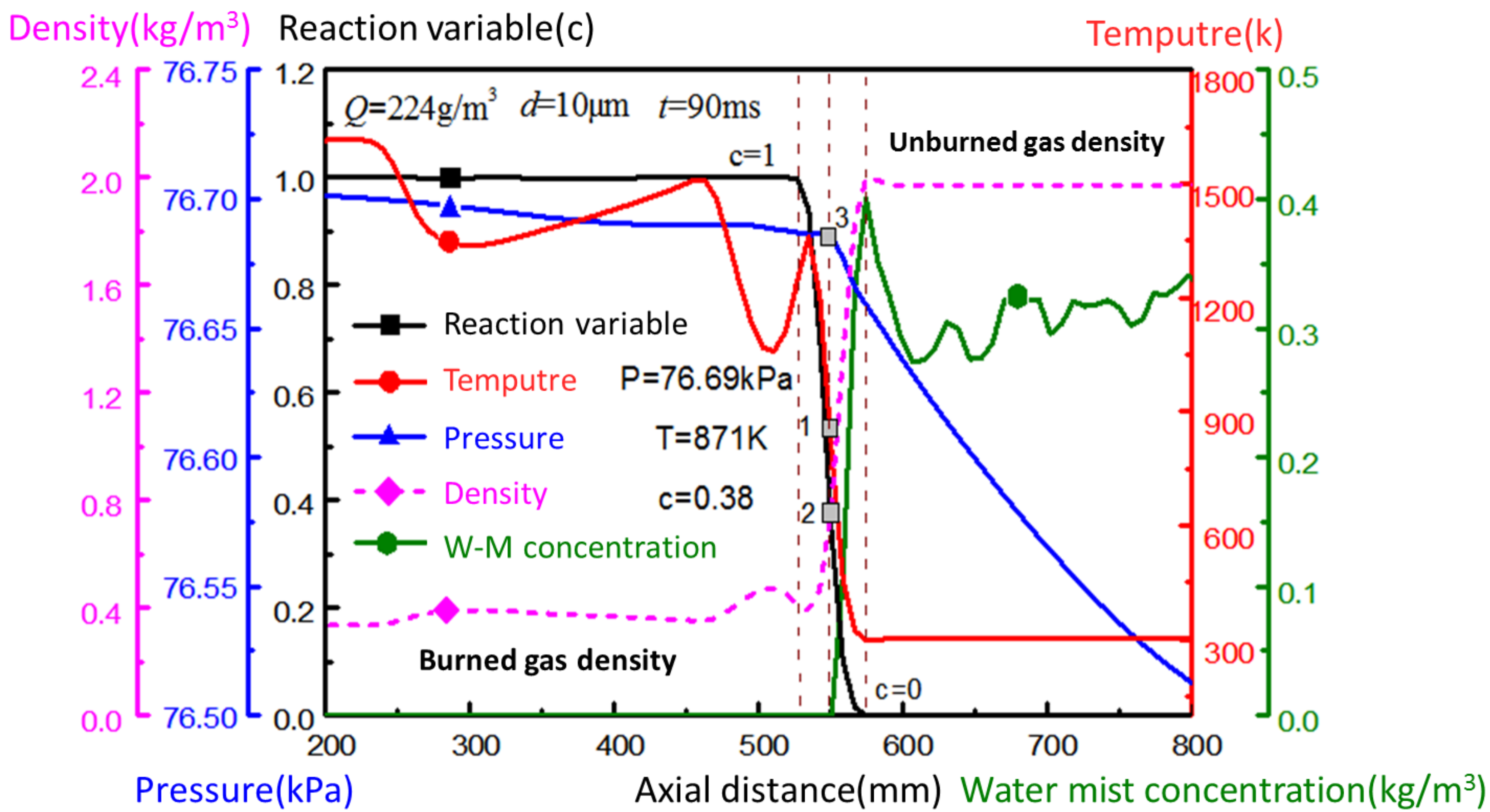


Figure 8 Explosion parameter curve of flame front

3 Numerical research

Figure9 shows the effect of water mist paremeter to the contact degree between water mist and flame front, as it shows, the largest diameter water mist could go through the flame front totally, with the diameter getting smaller, its crossing ability is getting weaker.

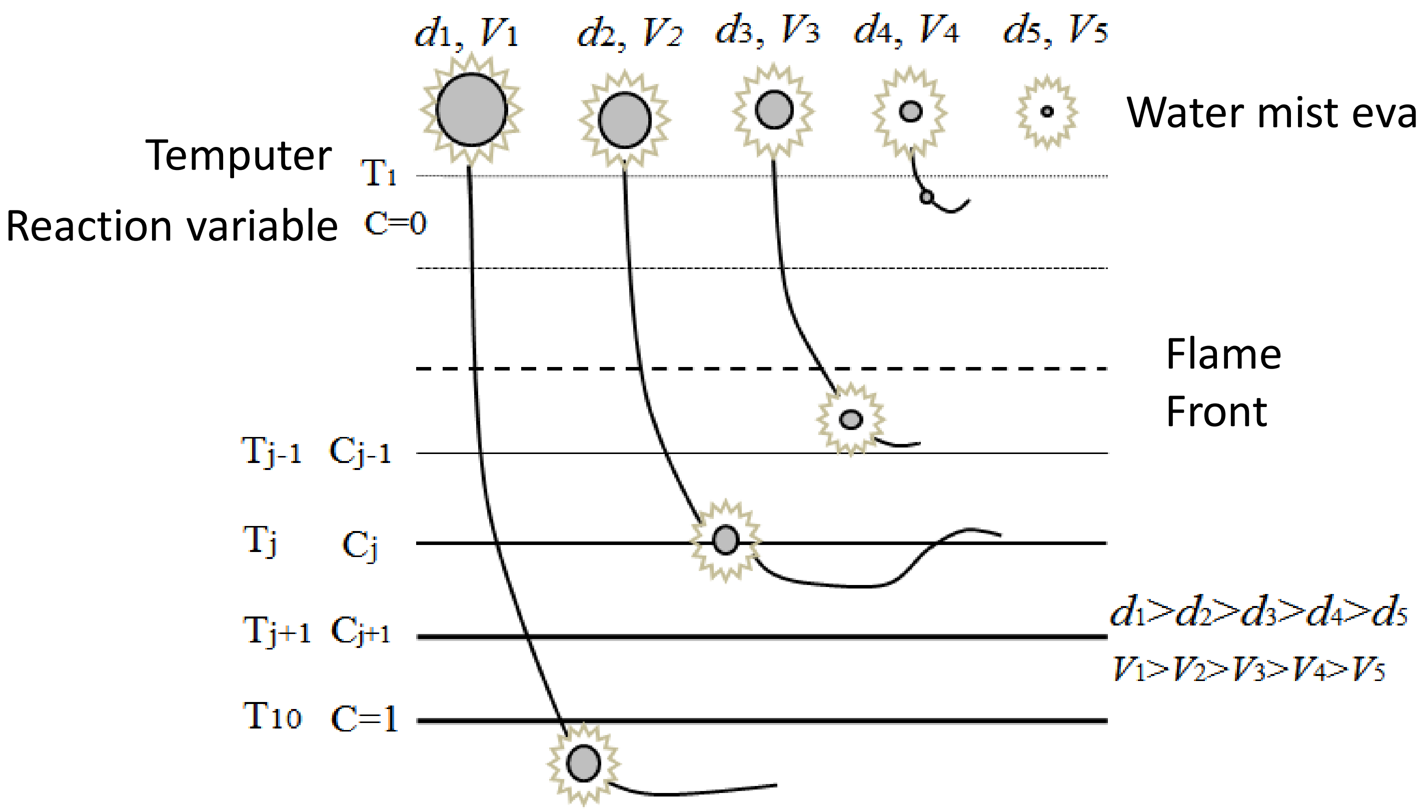


Figure 9 Effect of water mist parameter to contact between water mist and flame front

3 Numerical research

Figure10 shows comparison of energy absorbtion during the whole process.

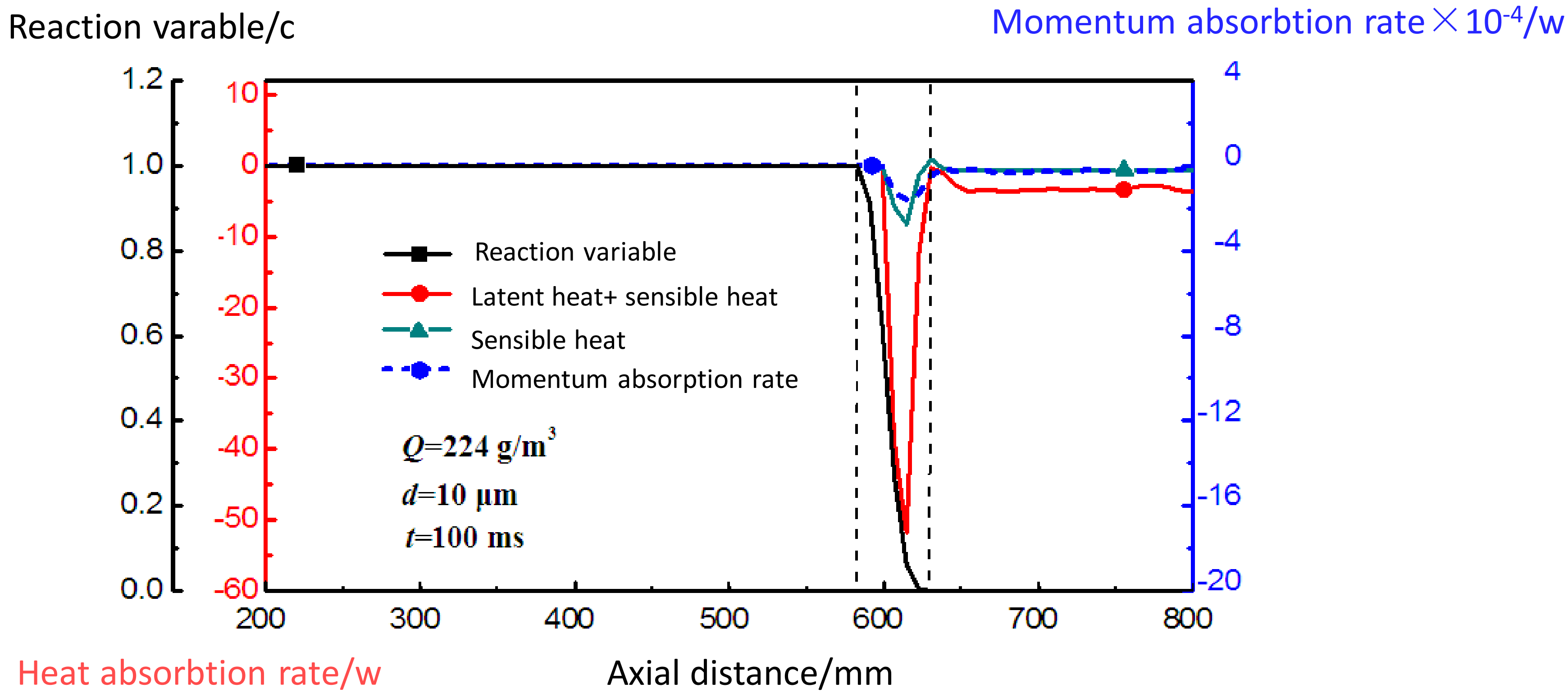


Figure 10 Comparison of energy absorption rate on axial inside vessel

- **Latent heat absorption, sensible heat absorption and momentum absorption all occur in the flame reaction zone ;**
- **Latent heat absorption is the main absorption way, which is much more than sensible heat; And they're both more than momentum absorption.**

3 Numerical research

As figure11 shows,

- ➢ If the water mist diameter is smaller than 30μm, in the reaction zone, the water mist could evaporate totally and absorb a large amount of heat;

- ➢ If it's 200μm, at reaction zone, the water mist couldn't evaporate totally, and the heat absorption is also much smaller.

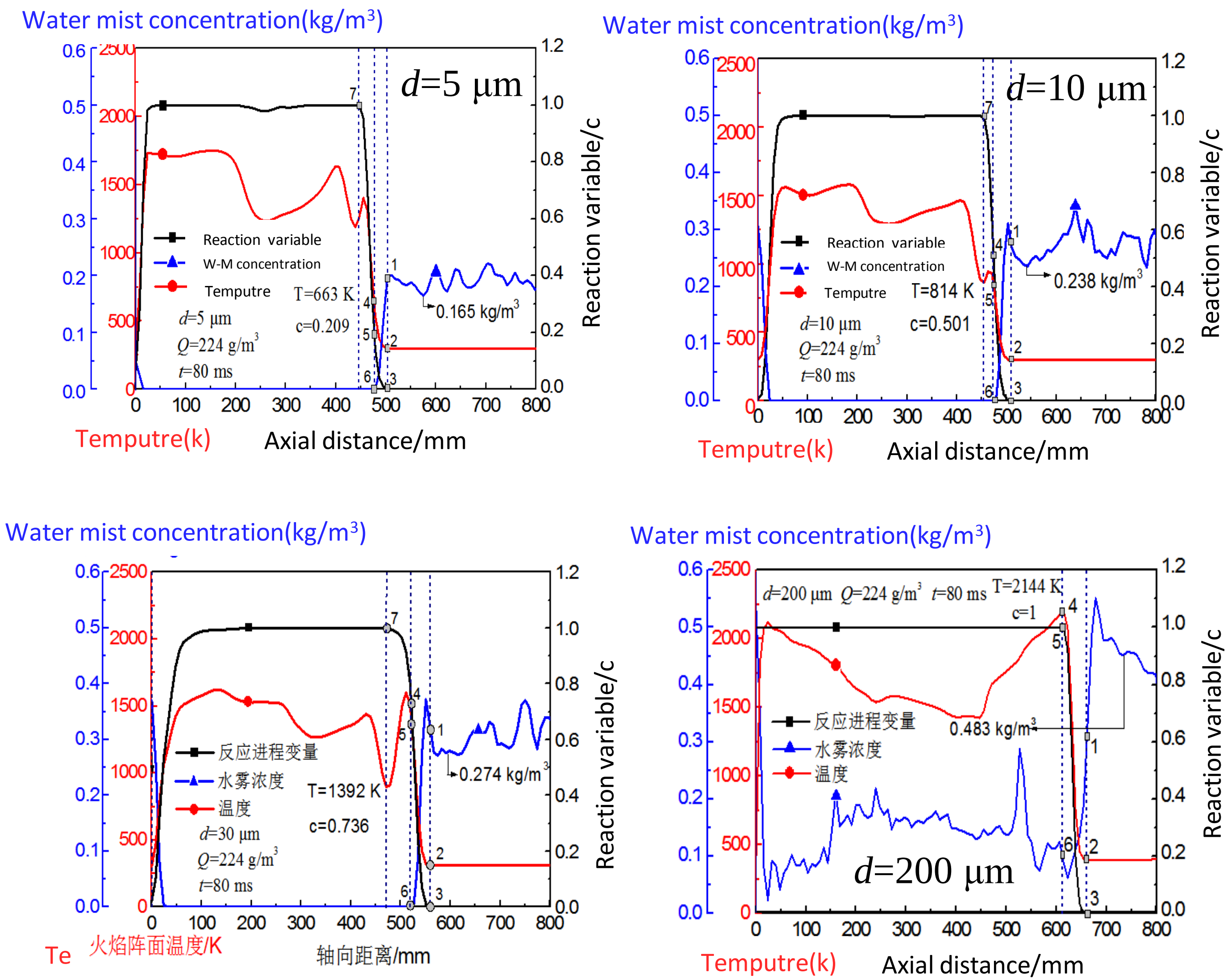


Figure 11 Effect of water mist diameter to contact degree between water mist and flame front

3 Numerical research

As figure12 ,13 shows, with diameter increasing, the evaporating of the water mist weakens.

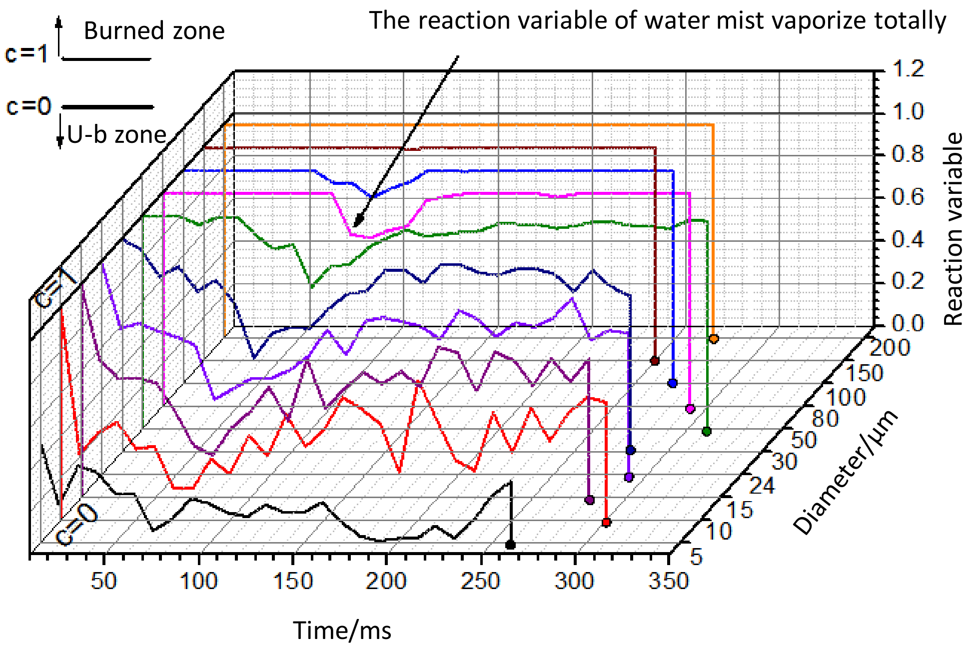


Figure 12 Effect of water mist diameter to the extent of the flame arriving at reaction zone

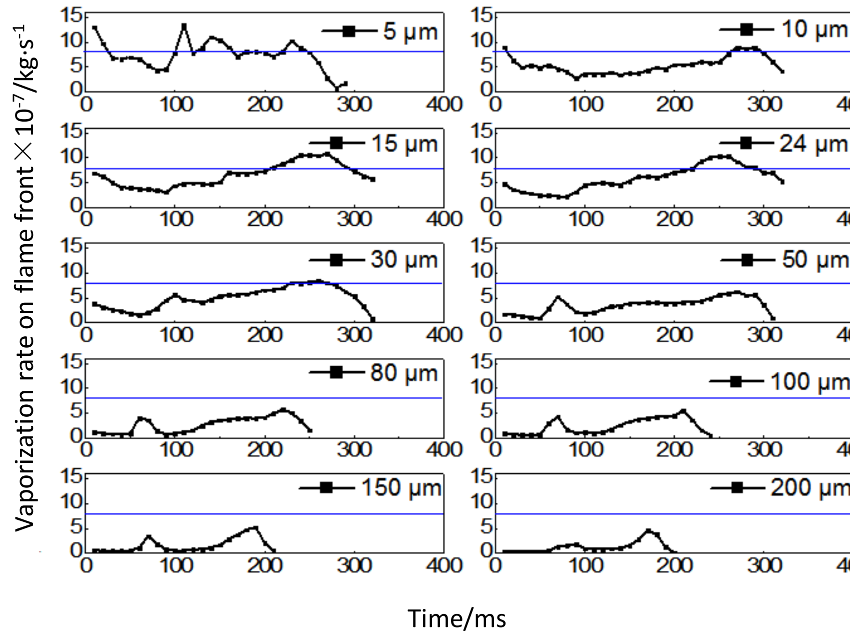
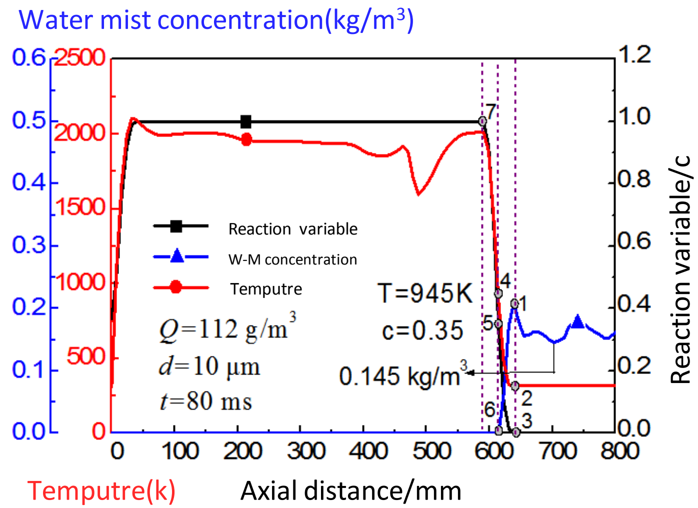


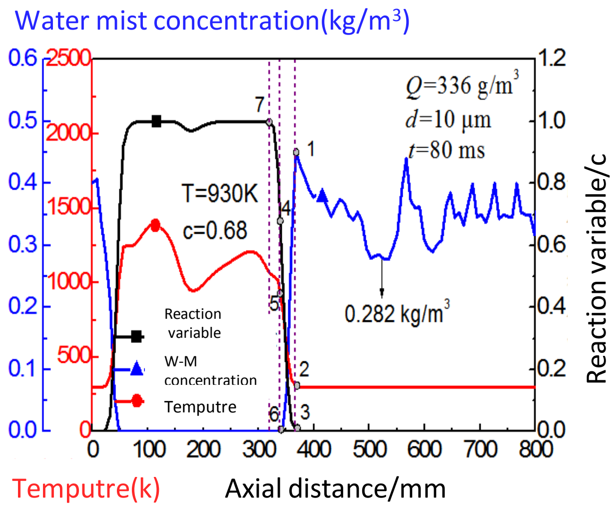
Figure 13 Effect of water mist diameter to the vaporization rate of water mist(c=0.01)

3 Numerical research

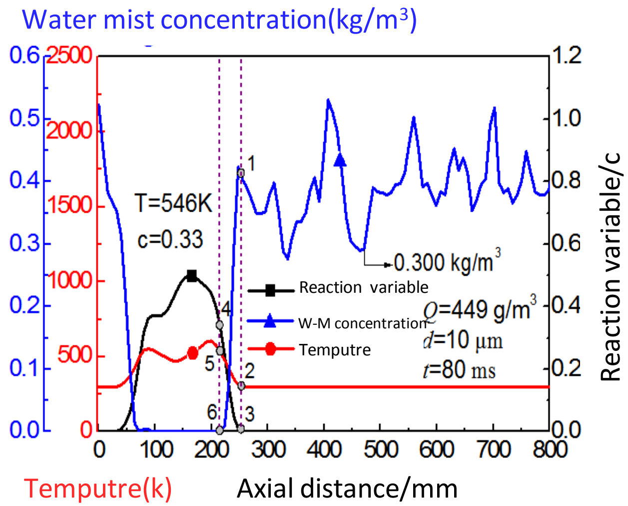
As figure14 shows, with the water mist concentration increasing, the suppression of the explosion reaction is enhanced, and the heat also release smaller.



(a) Q=112 g/m³



(b) Q=336 g/m³



(c) Q=449 g/m³

Figure 14 Effect of water mist concentration to contact degree between water mist and flame

As figure15 shows, with the water mist concentration increasing, the evaporation time of water mist is prolonged, when the concentration reach 674g/m³, the vaporization rate is very small. And it's also the same phenomenon as heat exchange.

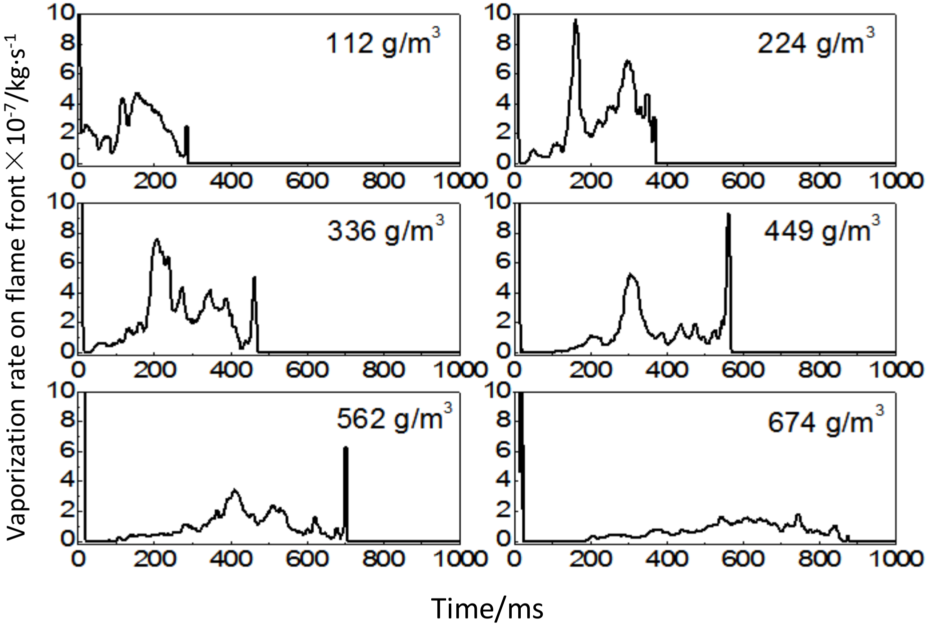


Figure 15 Effect of water mist concentration to the vaporization rate of water mist

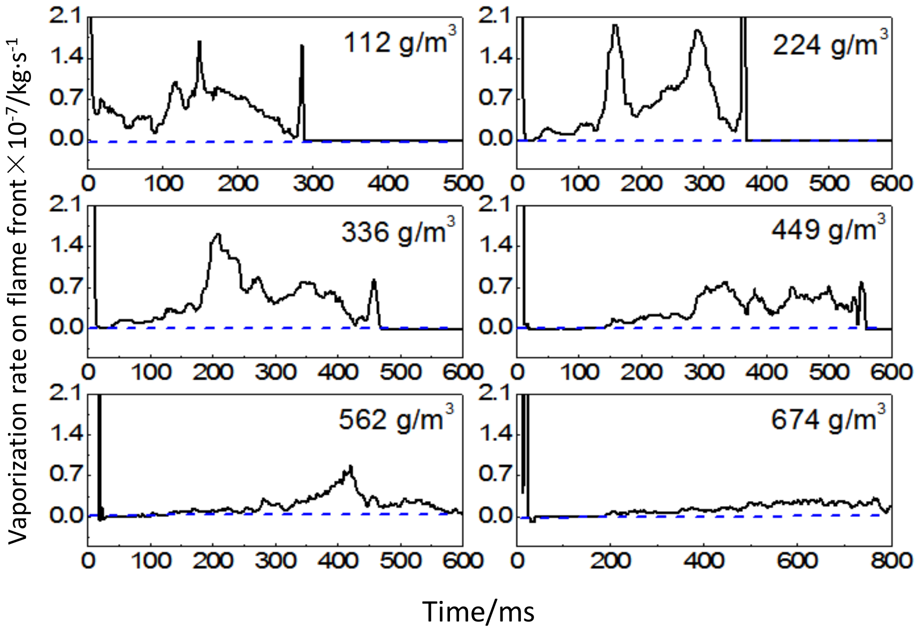


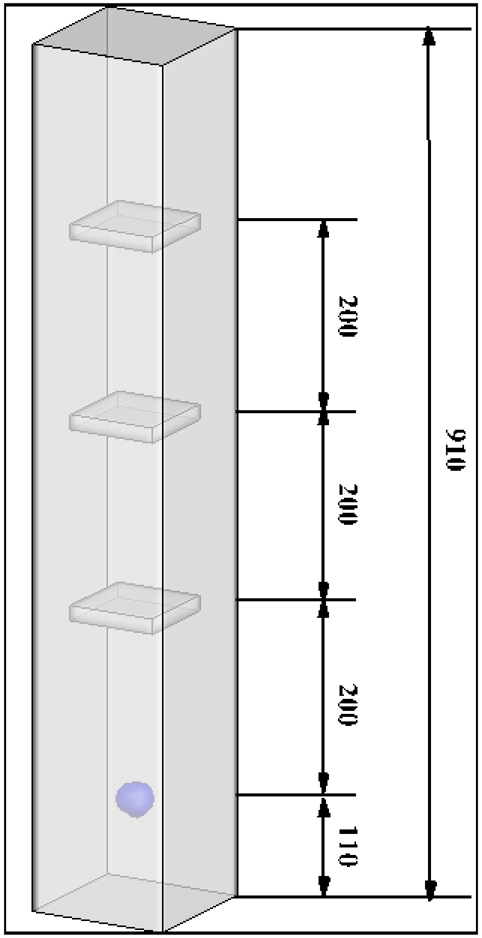
Figure 16 Effect of water mist concentration to the heat exchange rate of flame front

3 Numerical research

With Obstacles

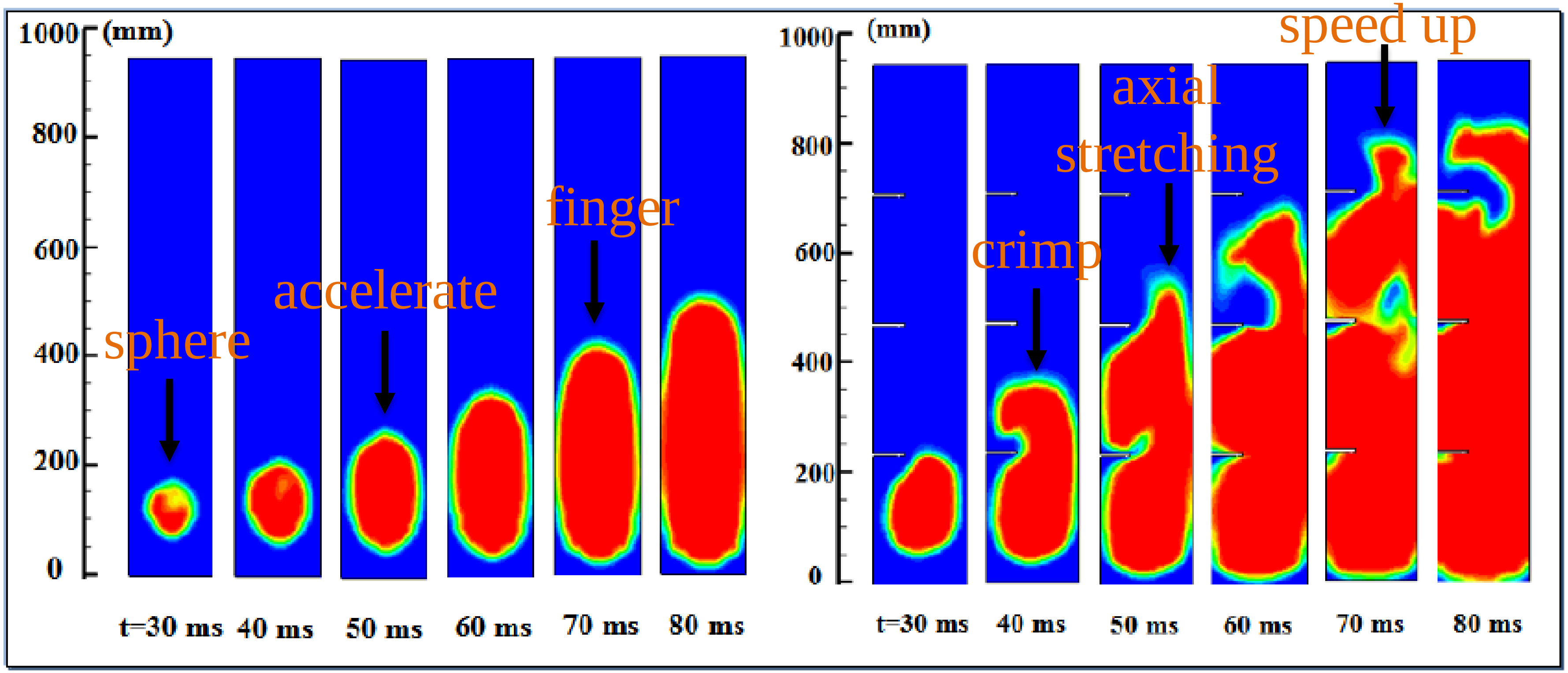
- The presence of obstacles in the vessel can obviously change the shape of flame surface and the structure of explosion flow field.
- Obstacles were set at equal intervals in the and the meshes around the obstacle zone were refined locally.

Items	Vessel (mm)	Obstacle (mm)	Igniting position
Length(mm)	150	150	At 110 mm above the bottom of the vessel
Width(mm)	150	5	
Height(mm)	910	50	



3 Numerical research

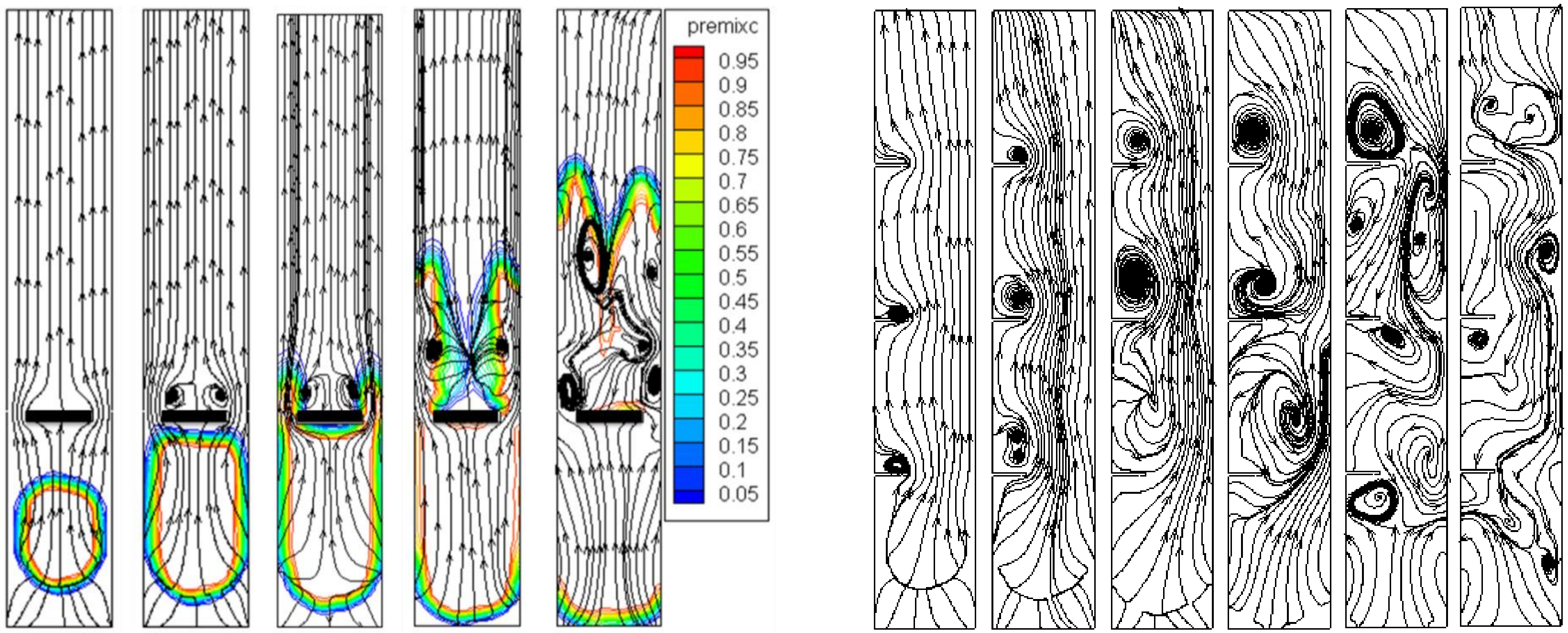
As figure17 shows, compared with no obstacle condition, if the flame front pass by obstacle, the flame would crimp and have an axial stretching, then would speed up propagating.



(a) *Without obstacle* (b) *Three obstacles*

Figure 17 Comparison of flame propagation process

As figure18 shows, when the flame front pass by obstacle, there would appear a vortex structure, at 40ms, two vortex structures appeared in the rear of first bottom obstacle.



(a) *Front view* (b) *Side view*

Figure 18 Effect of obstacle on flow flied

Figure19 shows that compared with no obstacle condition, the propagation speed can be increased greatly. Figure 20 shows the effect of spraying concentration on the maximum vorticity value in the vessel with three obstacles.

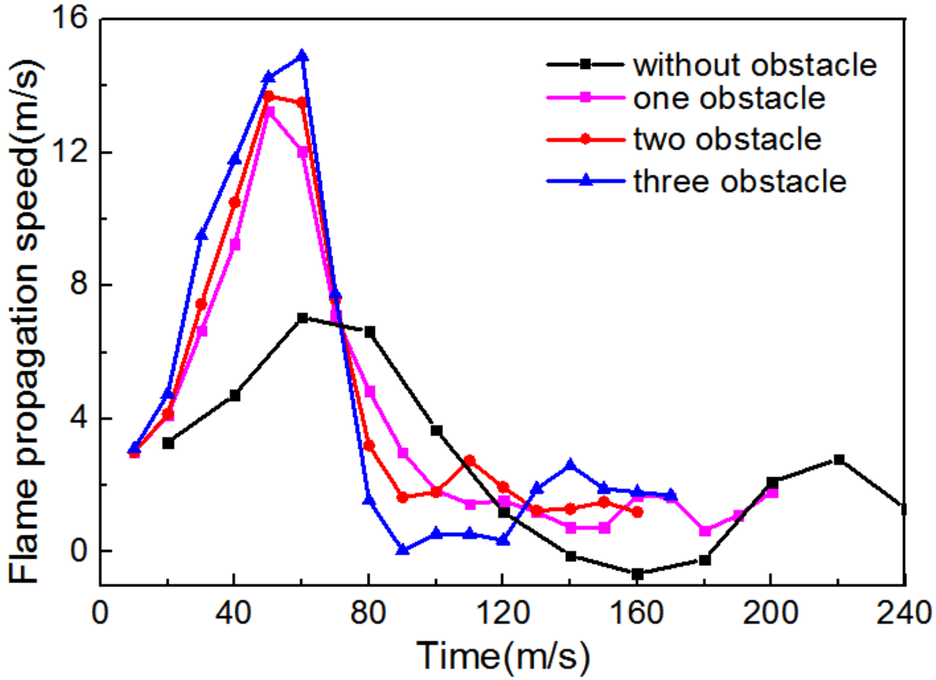


Figure 19 Effect of obstacles on flame propagation speeds

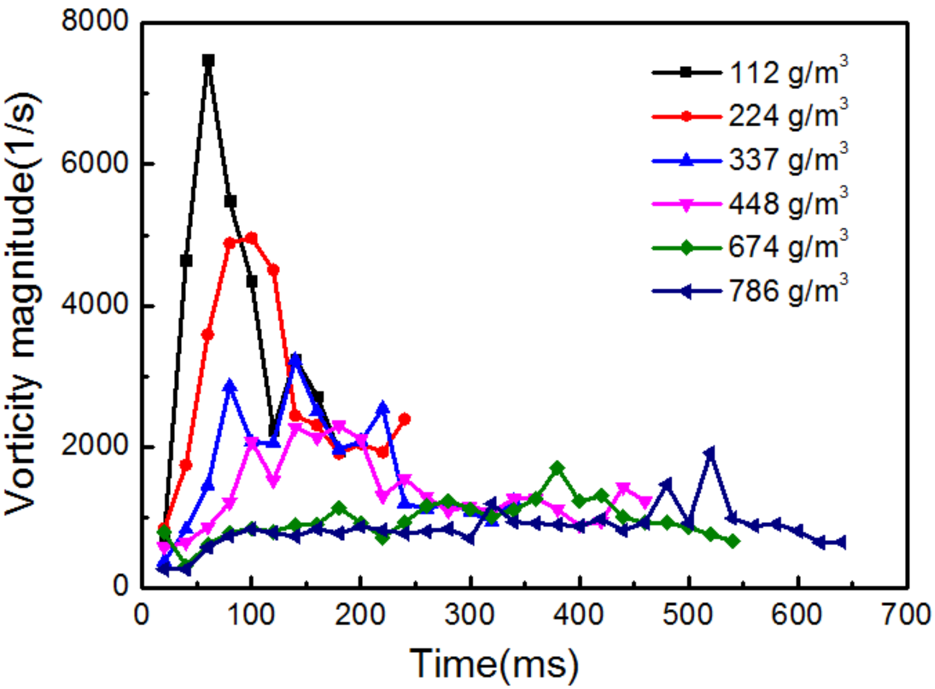


Figure 20 Effect of spraying concentration on vorticity magnitude

4 Main conclusions

1. **Water mist could influence explosion flow field by means of energy-absorption and flame front disturbing. The first aspect is good for suppression; The second one could enhance the flame turbulence, increase the explosion reaction rate, which lead to the enhancement of explosion.**

   In order to suppress the explosion effectively, the heat absorption function of water mist should be enhanced, and the influence of turbulence intensity should be monished.

2. **The water mist parameters (diameter, velocity and concentration) are critical factors which decide the suppression effect.**

   Larger diameter water mist have the smaller vaporization rate, could have a turbulence effect; Smaller diameter water mist have the bigger vaporization rate, could evaporate before reaching reaction zone totally.

3. **With the increase of water mist concentration, the heat exchange rate of gas-liquid two phase increases first and then decreases, but the total amount of heat exchange and the dilution effect are both increasing.**

Thank you for listening!