DISPERSION OF POWDER IN JETS SHOT OUT FROM FIRE-EXTINGUISHERS

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Abstract

Experimental fire fighting powder jet shoot-out has been studied by filming the formation of the powder cloud. On the basis of the theory of the free circular jet, powder concentrations have been determined as function of distance and time. These results are in good agreement with practical fire extinguishing experiences.

Introduction

Fire-extinguishers are qualified by extinguishing experimental pan fires. One of the conditions for efficient fire fighting is a good quality of fire fighting powder, the second is the character of the formation of the powder jet and the third factor is the human skill. The present paper does not deal with the qualification of powders, its goal is to reveal the properties of the powder jet. In this respect the following questions arise:

- the velocity of jet
- the width of jet, range of action
- the dispersion of the powder in the jet

These factors should be investigated as function of distance and time.

Theoretical aspects

In the case of a circular, steady-state turbulent jet, the velocity at a given point is:

$$v=\frac{3}{8\pi}\cdot\frac{p}{\eta_0 x}\cdot\frac{1}{\left(1+\frac{1}{4}\varepsilon^2\right)^2}, \tag{1}$$

where

$$\varepsilon=\frac{1}{4\eta_0}\sqrt{\frac{3p}{\pi}}\,\frac{x}{y}. \tag{2}$$

η_0 : virtual kinetic viscosity
p : impulse
y : distance from the central line
x : distance from the source of jet

The curve representing equation (1) is seen in Fig. 1. In the central line $\varepsilon=0$ and the maximum velocity is:

$$v_{\max}=\frac{3}{8\pi}\cdot\frac{p}{\eta_0 x}=\frac{2k}{x}. \tag{3}$$

According to the theory of a steady-state flow, the average velocity is the half of its maximum:

$$\bar{v}=\frac{v_{\max}}{2}. \tag{4}$$

Equations of this theory are valid for a given fluidum when there is no difference in the densities between the streaming material and the atmosphere.

These results are utilized in the investigation of powder jets. As the mass of the powder cannot be neglected in comparison to that of air, eq. (3) is used only formally. This means that k is an empirical constant.

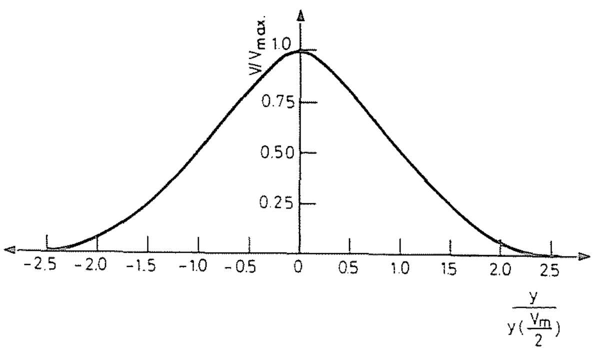

Fig. 1

Experimental

For studying the powder in the stream, a shoot-out of a fire-extinguisher was filmed by an S 8 camera.

The efficient extinguishing concentration of AP-100 powder was determined earlier in a laboratory equipment. This value was found to be 150 g/m^3.

The filling was 6 kg of AP – 100 powder. The fire-extinguisher operated with 1.4MPa of nitrogen. The frequency of the camera was 18/s. With the help of a montage apparatus the pictures were fixed, and the extension of the powder front was determined.

This is illustrated in Fig. 2. The distance of bars represents 1 m. The distance between the powder front peak and the nozzle was measured. These values are shown in Table 1 as function of the time.

The velocity of the extension of the powder front has to be equal to the average velocity in the steady state. This follows from the continuity theory. (This can also be seen in Fig. 2 because the advance of the front is piston-like.)

For this reason:

$$v_{\text{front}} = \bar{v} = \frac{k}{x}. \qquad (5)$$

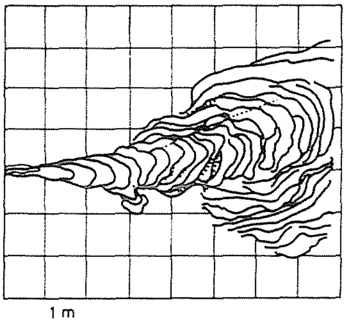

Fig. 2

Table 1

time t(s)	0.0222	0.0778	0.133	0.189	0.244	0.3	0.356	0.411
distance x(m)	0.72	1.62	2.16	2.61	2.93	3.20	3.60	3.90
time t(s)	0.467	0.522	0.578	0.633	0.639	0.744	0.80	0.911
distance x(m)	4.19	4.50	4.72	4.95	5.13	5.40	5.60	5.80

Upon integrating (5) we obtain that x (distance) is directly proportional to the square root of time:

$$x = \sqrt{2kt}. \qquad (6)$$

According to the data in Table 1, the $x - \sqrt{t}$ plot is a straight line (regression coeff. is 0.999).

The slope, $\sqrt{2k}$ is 6.44 $m/s^{1/2}$, thus k is 20.8 m^2/s.

From eq. (5) and (6) and k, the following equations are determined as function of distance and time: The average velocity:

$$\bar{v}=\frac{k}{x} \tag{7}$$

$$\bar{v}=\sqrt{\frac{k}{2t}}. \tag{8}$$

The growth of volume ($\dot{V}$) is the product of the average velocity and the cross section of the front, A:

$$\dot{V}=\bar{v}A \tag{9}$$

$$A=\pi x^2 \operatorname{tg}^2 \alpha. \tag{10}$$

where A is the cross section of stream at distance x, and α is the half angle of the cone-shaped stream. This angle is 7° according to Fig. 2

$$\dot{V}=k\pi x \operatorname{tg}^2 \alpha \tag{11}$$

$$\dot{V}=k^{3/2}\pi \sqrt{2t} \operatorname{tg}^2 \alpha. \tag{12}$$

Table 2

$\frac{x}{m}$	$\frac{t}{s}$	$\frac{v_m}{ms^{-1}}$	$\frac{V}{m^3}$	$\frac{\dot{V}}{m^3s^{-1}}$	$\frac{\bar{\rho}_p}{kgm^{-3}}$
0.5	0.006	41.6	0.002	0.49	1.22
1	0.024	20.8	0.016	0.98	0.61
1.5	0.054	13.9	0.053	1.48	0.41
2	0.096	10.4	0.13	1.97	0.304
2.5	0.15	8.32	0.25	2.46	0.243
3	0.22	6.93	0.43	2.96	0.203
3.5	0.29	5.94	0.68	3.45	0.174
4	0.38	5.2	1.01	3.94	0.152
4.5	0.49	4.62	1.44	4.43	0.135
5	0.6	4.16	1.97	4.93	0.121
5.5	0.73	3.78	2.63	5.42	0.111
6	0.87	3.47	3.41	5.91	0.102
6.5	1.02	3.2	4.34	6.4	0.097
7	1.18	2.97	5.42	6.9	0.087
7.5	1.35	2.77	6.66	7.39	0.081
8	1.54	2.6	8.08	7.88	0.076
8.5	1.74	2.45	9.7	8.37	0.072
9	1.95	2.31	11.5	8.87	0.068
9.5	2.17	2.19	13.5	9.36	0.064
10	2.41	2.08	15.8	9.85	0.061

Table 3

$\frac{t}{s}$	$\frac{x}{m}$	$\frac{v_m}{ms^{-1}}$	$\frac{V}{m^3}$	$\frac{\dot{V}}{m^3s^{-1}}$	$\frac{\bar{\rho}_p}{kg\,m^{-3}}$
0.1	2.04	10.19	0.13	2.01	0.3
0.2	2.88	7.21	0.38	2.84	0.21
0.3	3.53	5.88	0.69	3.48	0.17
0.4	4.04	5.1	1.07	4.02	0.15
0.5	4.56	4.56	1.5	4.49	0.13
0.6	4.99	4.16	1.97	4.92	0.122
0.7	5.39	3.85	2.48	5.32	0.113
0.8	5.77	3.6	3.03	5.68	0.106
0.9	6.12	3.4	3.61	6.03	0.1
1	6.045	3.22	4.23	6.35	0.094
1.1	6.76	3.07	4.88	6.66	0.09
1.2	7.06	2.94	5.56	6.96	0.086
1.3	7.35	2.83	6.27	7.24	0.083
1.4	7.63	2.72	7.00	7.52	0.08
1.5	7.89	2.63	7.77	7.78	0.077
1.6	8.15	2.55	8.56	8.04	0.075
1.7	8.4	2.47	9.37	8.28	0.072
1.8	8.65	2.4	10.21	8.52	0.070
1.9	8.89	2.34	11.07	8.76	0.068
2.0	9.12	2.28	11.96	8.99	0.067

The volume of the stream is

$$V = \frac{\pi x^3}{3} \mathrm{tg}^2\,\alpha \tag{13}$$

$$V = \frac{\pi (2kt)^{3/2}}{3} \mathrm{tg}^2\,\alpha. \tag{14}$$

With eqs. (7)–(14), velocities, growth of volumes and volumes were calculated as function of distance and time. These are summarized in Tables 2 and 3. The last columns in the Tables are the average densities, that is the concentration of the powder, $\bar{\rho}_p$ in the front. This latter was calculated with the following equation:

$$\bar{\rho}_p = \frac{\dot{m}}{\dot{V}} = \frac{\dot{m}}{k\pi x\,\mathrm{tg}^2\,\alpha} = \frac{k'}{x} \tag{15}$$

$\dot{m}$ is the mass flow of the powder. This datum is provided by the rate of the mass decrease of the fire extinguisher during the shooting time.

This is 2.4 kg/4 s = 0.60 kg/s.

These results had to be checked by extinguishing experiments. For this purpose the same fire-extinguisher was used in extinguishing pan-fires. As shown in Fig. 3, five rectangular pans of 0.6 m length and 0.3 m width were placed side by side. This fuel fire of 3 m length was suppressed with our

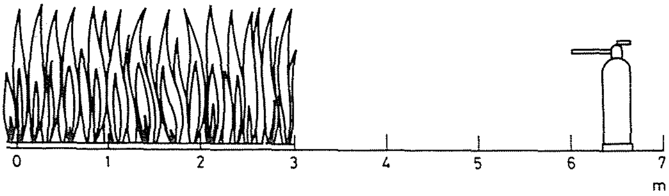

Fig. 3

extinguisher. The extinguishing experiments were carried out from different distances (5, 6, and 7 meters) from the end of last pan, as seen in Fig. 3. The extinguishing experiments carried out by a skilful person were successful from 5 and 6 meters, but from 7 m the fire at the end of the last pan could not be suppressed and after the attempt it flashed back.

Discussion

Eq. (1) is valid for a jet with constant density. In our case eq. (5) is used analogously to (1) because there was a good correlation between the measured and calculated data.

The average powder concentration is inversely proportional to the distance from the jet source. Perpendicularly to jet direction (y), jet velocity decreases because of the growth of moving air (the front gets wider). This excess of air causes the dilution of the powder. Accordingly in y direction the concentration decrease is similar to a velocity decrease. (Fig. 1). Thus it can be expected that the concentration is maximum in the axis of stream and the average is the half of it.

According to Table 3, at 8 m from the source the average concentration is 0.076 kg/m^3, thus the maximum in the axis is 0.152 kg/m^3. Consequently, from over this distance the powder jet could not extinguish even a light of a match.

According to Fig. 3, the extinguishing experiment was successful from 5 and 6 m. Over 6 m, the average concentration is about 100 g/m^3, thus the maximum in the axis is 200 g/m^3. Concerning the width of the flames, the average in the flame width can be estimated to be 150 g/m^3, i.e. equal to the efficient concentration of the AP 100 powder.

According to these it is proved that there is no contradiction between real fire fighting experiments and calculated data. It is justified to assume that the efficient concentration of powder determined in the laboratory is suitable for extinguishing real pan fires.

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References

1. SCHLICHTING, H.: Grenzschicht-Theorie, Verlag G. Braun, Karlsruhe 1965

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