特別寄稿

Study of Optimal Dust Collecting and Ventilation Systems for Air Pollution Control

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1. Introduction

First of all, it is necessary to make clear the exhaust characteristics of hoods to know how the air from surroundings and contaminated gas from sources mix in the hoods.

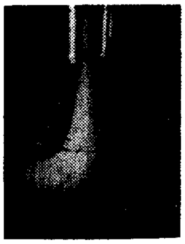
Next, experimental researches has been done for about twelve years being founded on the fact above mentioned, and several equations for design are got.

2. Canopy Hoods[1),2),3),4),5),6),7),8),9),10),11),12)]

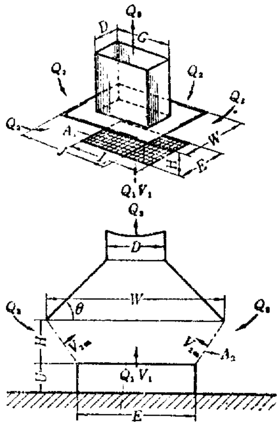
Nomenclature(See Fig. 2·1(a), (b),)

$K=Q_2/Q_1$: Flow ratio
A: Surface area, m^2
W: Minor side or diameter of a hood, m
J: Major side or diameter of a hood, m
E: Minor side or diameter of a source, m
L: Major side or diameter of a source, m
H: Height of a hood from the surface of a source, m
D: Minor side or diameter of a duct, m
U: Height of a source from the floor, m
$\gamma=E/L$: Aspect ratio, or specific gravity, kg/m^3
θ: Hood's angle, °
n: Safety number for overflow,
v: Flow velocity, m/s
Q: Volume rate of flow, m^3/min or m^3/min/m
Δt: Temperature difference, °C

Suffix
1: Contaminant
2: Surroudings
3: Mixed flow of 1 and 2
L: Limit value
m: Mean value
D: Design value



(a)



(b)

Fig. 2·1

2.1 Fundamental Characteristics of canopy hoods

Generally, a hood inhales contaminated gas Q_1 and air from surroundings Q_2 simultaneously, and then exhausts volume Q_3 which is equal to Q_1+Q_2 as far as Q_1 does not overflow from the hood. Therefore, the most important thing we must know at the beginning of researches is how the shapes of discontinuous boundary lines being formed by the combination flows of Q_1 and Q_2 change under the influence of flow ratio $K=Q_2/Q_1$.

Laplacian $\frac{\partial^2\phi}{\partial x^2}+\frac{\partial^2\phi}{\partial y^2}=0$ can be solved by numerical analysis. For a function $U_k(x,y)$ of two variables, let the xy-plane be divided into a net work or lattice of squares of side h, by drawing the two families of parallel lines

$$x=mh,\quad m=0,1,2,3\cdots\cdots,$$
$$y=nh,\quad n=0,1,2,3\cdots\cdots,$$

as indicated in Fig. 2·2.

With reference to the figure, the forward first difference quotient of $U(x,y)$ with respect to x is

$$\left.\begin{aligned}U_x&=\frac{U(x+h,y)-U(x,y)}{h}\\U_x&=\frac{U(x,y)-U(x-h,y)}{h}\end{aligned}\right\}\qquad(2.1)$$

$$U_{xx}=\frac{U(x+h,y)-2U(x,y)+U(x-h,y)}{h}.\qquad(2.2)$$

We have in exactly the same manner

$$U_{yy}=\frac{U(x,y+h)-2U(x,y)+U(x,y-h)}{h}.\qquad(2.3)$$

Laplace's equation for two dimensions is $\partial^2V/\partial X^2+\partial^2V/\partial Y^2=0$.

Replacing $\partial^2V/\partial X^2$ and $\partial^2V/\partial Y^2$ by U_{xx} and U_{yy}, respectively, we get

$$\begin{aligned}U(x,y)=\frac{1}{4}\{&U(x+h,y)+U(x,y+h)\\&+U(x-h,y)+U(x,y-h)\},\end{aligned}\qquad(2.4)$$

from which we have

$$\left.\begin{aligned}U_1&=\frac{1}{4}(a_2+a_{22}+U_2+U_4)\\U_2&=\frac{1}{4}(a_2+U_1+U_3+U_5)\\&\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\\&\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\end{aligned}\right\}.\qquad(2.5)$$

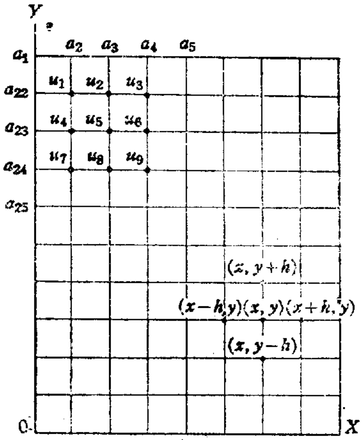


Fig. 2·2

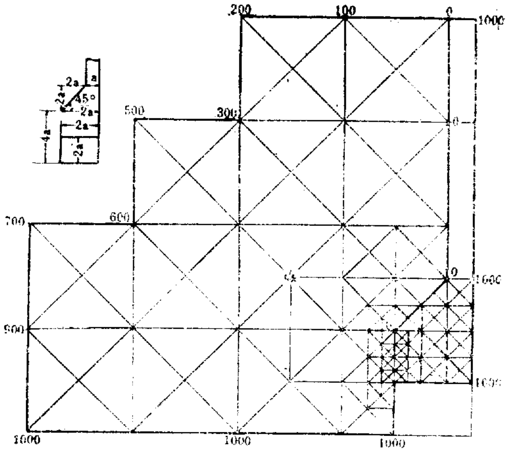


Fig. 2·3

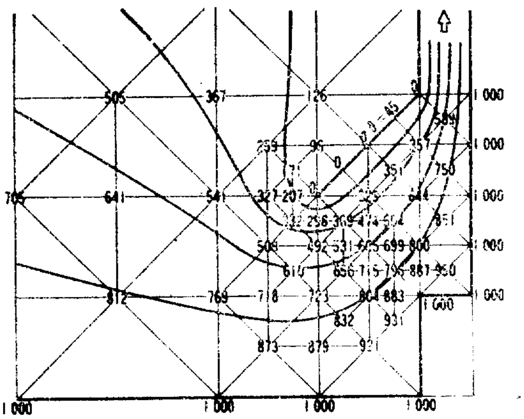


Fig. 2·4

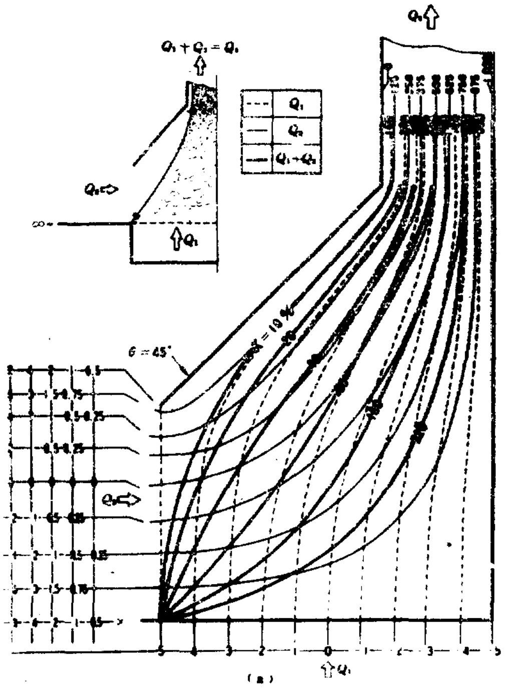


Fig. 2·5

Fig. 2·6

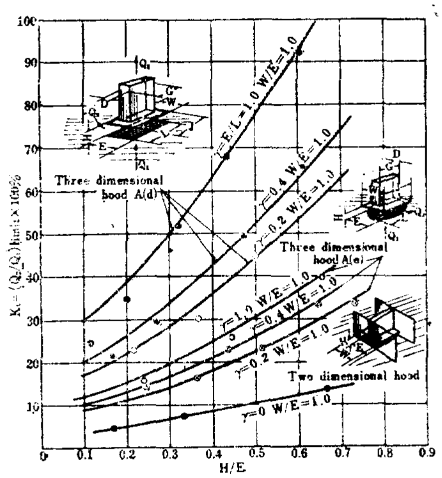


Fig. 2·7

This equation shows that the value of U at any interior lattice point is the arithmetic mean of the value of U at the four lattice points nearest it. A solution is shown in Fig. 2·3 and Fig. 2·4, and, then, two streams of Q_1 and Q_2 are combined as shown in Fig. 2·5. Fig. 2·6 shows that theoretical boundary lines and practical ones coincide comparatively well.

As the results of experimental researches, W/E, H/E, $\gamma=E/L$ and Δt influence considerably exhaust characteristics of hoods which are shown in Fig. 2·7 for an example.

2.2 Design method of canopy hoods by "Flow Ratio Method"

If the fundamental characteristics of canopy hoods are well understood, rational canopy hoods are to be designed as follows: (See Fig. 2·7)

(A) As the size of the source of contaminant E, L, U, volume rate of flow Q_1, characteristics of contaminated gas t_1, γ_1, etc, the height H of the hood to be settled and the condition for the work are to be known at the design of hood, shape and sizes of the hood θ, D, W, J, can be decided.

(B) Next, the value of K_L is calculated by the following equations.

1) Two dimensionals:

$$K_L=\{1.8(H/E)+1.7\}\{0.64(W/E)^{-1.33}+0.36\}\ \% \tag{2.6}$$

where, $D/E\geqq 0.2$, $H/E\leqq 0.7$, $0.5\leqq W/E\leqq 3.0$

2) Three dimensionals:

ⓐ Rectangular hood——Rectangular source

$$K_L=\{140(H/E)^{1.43}+25\}\left\{\frac{0.82}{(W/E)^{3.4}}+0.18\right\}\{0.53\gamma+0.47\}\ \% \tag{2.7}$$

ⓑ Four corners of the source are made round in ⓐ

$$K_L=\{8(H/E+1.0)^{2.6}-2.0\}\left\{\frac{1.05}{(W/E)^{1.4}}+0.4\right\}\{2.5(\gamma+0.01)^{0.06}-1.5\}\ \% \tag{2.8}$$

where, $D/E\geqq 0.3$, $H/E\leqq 0.7$, $1.0\leqq W/E\leqq 2.0$,

$0.2 \leqq \gamma \leqq 1.0$

(C) K_D, Q_3, V_{2m} are calculated by the following equations.

$$K_D = n \cdot K_L \quad (n \geqq 3) \tag{2.9}$$

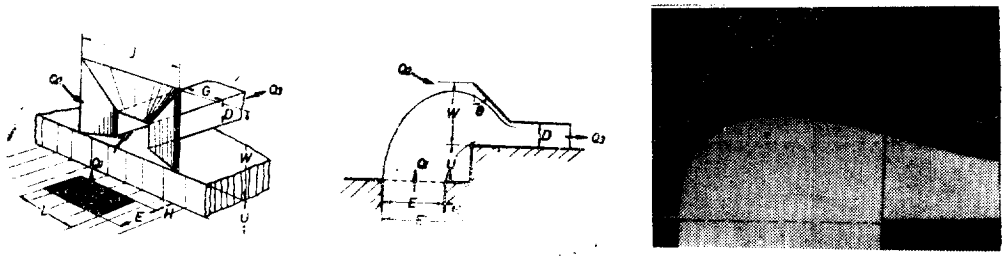
$$Q_3 = Q_1 (1 + K_D) \tag{2.10}$$

$$V_{2m} = \frac{Q_2}{A_2} = \frac{Q_3 - Q_1}{A_2} \tag{2.11}$$

(D) If the value of v_{2m} is known at design, the calculation becomes more simple.

(E) Temperature difference Δt are considered.

$$K_{L(\Delta t = \alpha)} = K_{L(\Delta t = 0)} + \frac{3}{2500} \Delta t \tag{2.12}$$



(a) (b) (c)

Fig. 3·1

Therefore, we have the following equation from Eq. (2.10), and Eq. (2.12).

$$Q_3 = Q_1 \left\{ 1 + n \left(K_{L(\Delta t = 0)} + \frac{3}{2500} \Delta t \right) \right\} \tag{2.13}$$

3. Lateral Hoods[13),14),15),16)]

Nomenclature (See Fig. 3·1 (a), (b), (c),)

A_1: Surface area of contaminant, m^2

A_D: Opening area of a duct, m^2

D: Height of a duct, m

E: A side of a source, m

E': Imaginary a side of a source, m

G: Width of a duct, m

L: Another side of a source, m

H: Hood's set distance on axial from an opening of a hood, m

J: Width of a flange, m

n: Safety number for overflow

Q: Volume rate of flow, m^3/min or $m^3/min/m$

$K = Q_2/Q_1$: Flow ratio, % or non dimension

U: Height of a hood from the floor, m

W: Height of a hood flange, m

θ: Hood's angle, °

v: Flow velocity, m/s

$\gamma = E/L$: Aspect ratio, non dimension

Suffix

1: A symbol related to contaminants

2: A symbol related to surroundings

3: A symbol related to mixed flow of 1 and 2

L: Limit value to overflow

D: Design value

3.1 Fundamental characteristics of lateral hoods

Ths inhaling aspect of combination flow of Q_1 and Q_2 can be also solved by the same numerical analysis which are used in the cases of canopy hoods.

Fig. 3·2 is an example and Fig. 3·3 is a comparison of a theoritical result and a practical one.

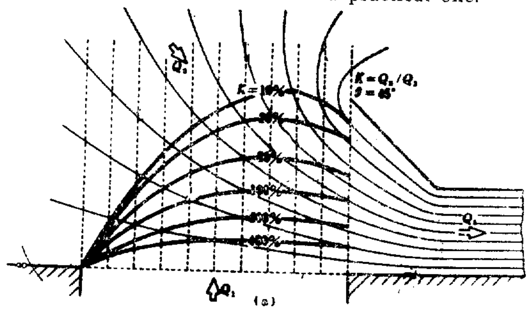


Fig. 3·2

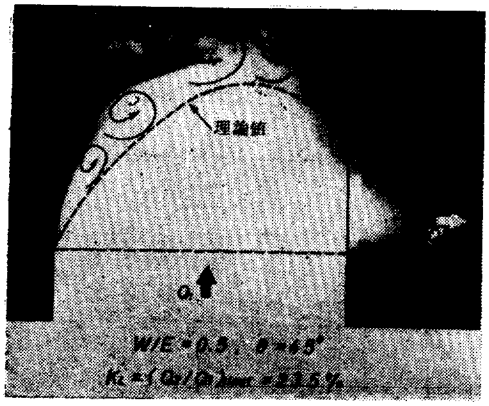


Fig. 3·3

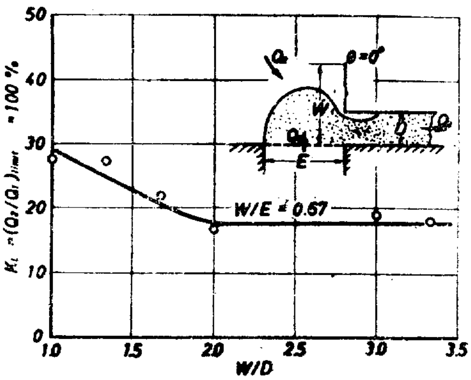


Fig. 3·4

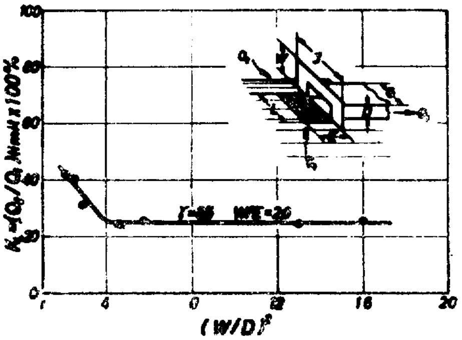


Fig. 3·5

By the way, we can find from this photograph that both do not coincide and are a little slip out of the places; this is because that as both sinks of Q_1 and Q_2 are different, inertia acts in the case of practical flows.

Here, worthy points of special mention are as follows:

1) The values of W/D which show the effect of hood's flange are very important. That is, W/D scarcely influences on K_L within the limit of $W/D \geqq 2.0$, but the values of K_L increase abruptly from the points beyond the limit of $W/D < 2.0$. Therefore, we may say we should absolutely select the values within $W/D \geqq 2.0$. (See Fig. 3·4, Fig. 3·5)

2) The values of θ influence remarkably on K_L, and we should adopt $\theta = 0°$ always. (See Fig. 3·6)

3) The values of W/E are important, and we can find out from Fig. 3·7 that we should adopt following values:

ⓐ Two dimensional lateral hood, $0.5 \leqq W/E \leqq 1.0$

ⓑ Three dimensional lateral hood, $1.0 \leqq W/E \leqq 2.0$

4) Just same as in the cases of canopy hoods, lateral hoods also should be set as far as near to the sources of contaminant. Fig. 3·8, Fig. 3·9 clearly show the above mentioned facts; that is, as the values of U/E

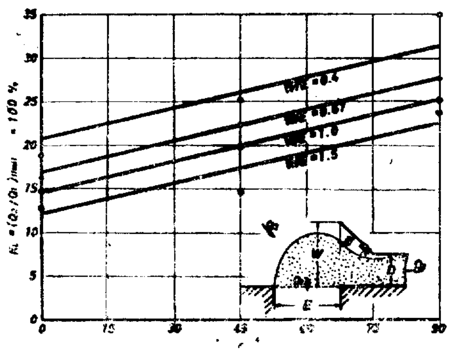


Fig. 3·6

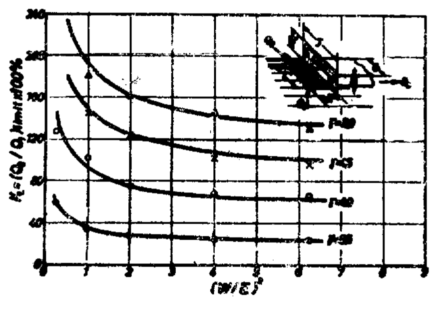


Fig. 3·7

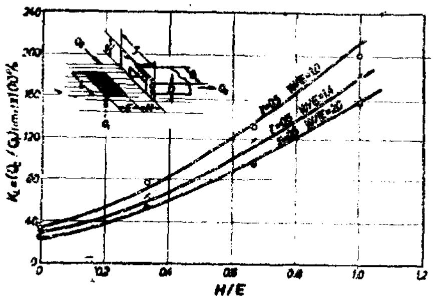


Fig. 3·8

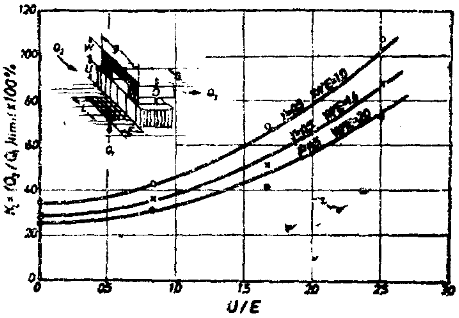


Fig. 3·9

or H/E increase, the values of K_L increase in all cases.

3.2 Design method of lateral hoods by "Flow Ratio Method"

(A) As the size of the source of contaminants E, L, the volume rate of flow Q_1 or flow velocity v, the distance H, the height U and the conditions for the work are made known at the sizes of the hood θ, W, J, D, G can be decided easily.

(B) Next, the value of K_L is calculated by the following equations.

1) Two dimensionals: (See Fig. 3·10)

$$K_L=10^{0.105U/E'}(0.119\theta+14.5)\{1.04(W/E')-0.04\}\left\{\frac{0.93}{1-H/E'}\right\}\% \quad (3.2)$$

where, $W/D\geqq 2.0$

$0°\leqq\theta\leqq 90°$

$0.2\leqq W/E'\leqq 1.5$

$0\leqq U/E'\leqq 1.6$

$0.05\leqq H/E'\leqq 0.5$

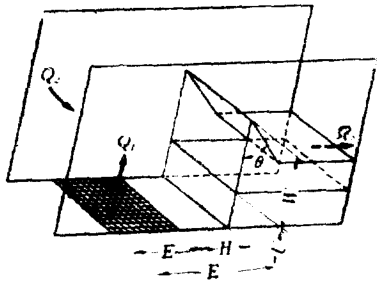


Fig. 3·10

2) Three dimensionals:

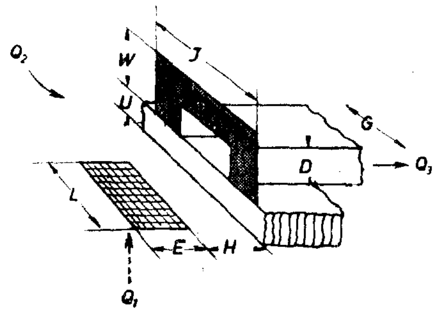


Fig. 3·11

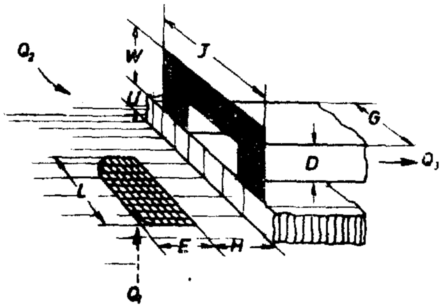


Fig. 3·12

ⓐ Rectangular source (See Fig. 3·11)

$$K_L=2.9\{5.0(W/E)^{-1.48}+7.0\}\{1.9\gamma^{1.66}+0.4\}\{5.2(H/E)^{1.4}+1.0\}\{0.32(U/E)^{2.0}+1.0\}\% \quad (3.2)$$

ⓑ Two corners of the source are made round inⓐ (See Fig. 3·12)

$$K_L=1.29\{7.0(W/E)^{-1.62}+16.0\}\{1.9\gamma^{1.66}+0.4\}\{5.0(H/E)^{1.4}+1.0\}\{0.45(U/E)+1.0\}\% \quad (3.3)$$

where, $\theta=0°$, $0\leqq\gamma\leqq 2.0$, $W/D\geqq 2.0$, $0.7\leqq W/E\leqq 2.5$, $0\leqq H/E\leqq 1.0$, $0\leqq U/E\leqq 2.5$

(C) Then, K_D and Q_3 are calculated by the following eqnations:

$$K_D = n \times K_L \quad (3.4)$$

$$Q_3 = Q_1(1 + K_D) \quad (3.5)$$

where, $n \geqq 3$

4. Push-Pull Hoods

A hood which acts as push flow and pull flow always co-operate each other is called a push-pull hood; this means that these types of hoods are quite effective and rational from all angles comparing with pull type hoods, especialy when the distances between hoods and contaminated sonrces are relatively far, intereception from sourroundings such as air curtain, air shutter and air tunnel is necessary and, furthermore, ideal sectional or whole ventilation is necessarily to be intended.

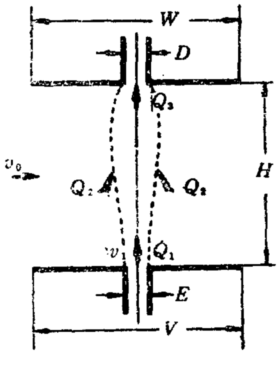


Fig. 4·1

Nomenclature (See Fig. 4·1)

E: Width of push opening, m

D: Width of pull opening, m

V: Push side base length, m

W: Pull side flange length, m

H: Arrival distance, m

v_1: Flow velocity from push opening, m/s

v_0: Flow velocity from lateral side, m/s

Q: Volnme rate of flow, m^3/min

m: Safety number,

$K = Q_2/Q_1$: Flow ratio, % or non dimension

Suffix

1 : A symbol related to be pushed

2 : A symbol related to surroundings

3 : A symbol related to be pulled

L: Limit value to overflow

D: Design value

S: Limit value to intercept

B: Limit value to be broken

4.1 Fundamental characteristics of push-pull hoods

There are three fundamental flow patterns in push-pull hoods as shown in Fig. 4·2. Being always obliged to adopt best type in response to the case, we must know well those flowing characteristics and design them.

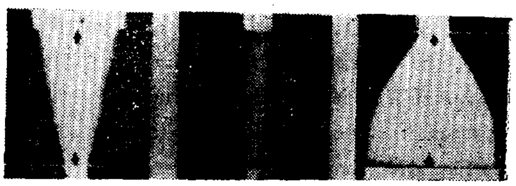


Fig. 4·2

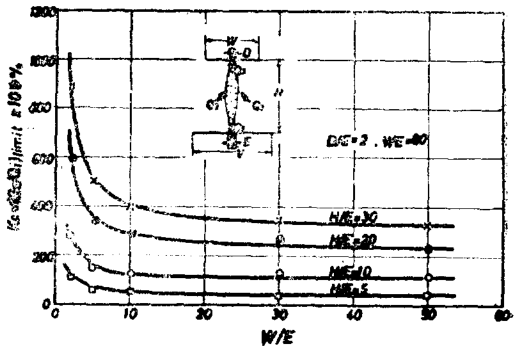


Fig. 4·3

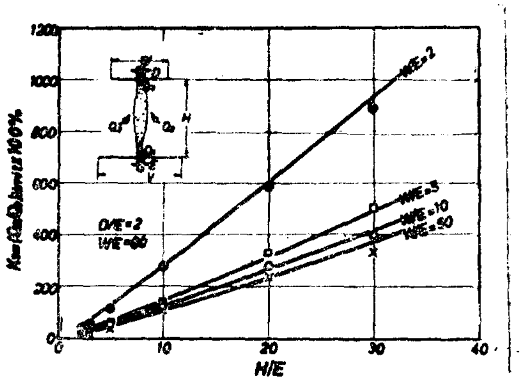


Fig. 4·4

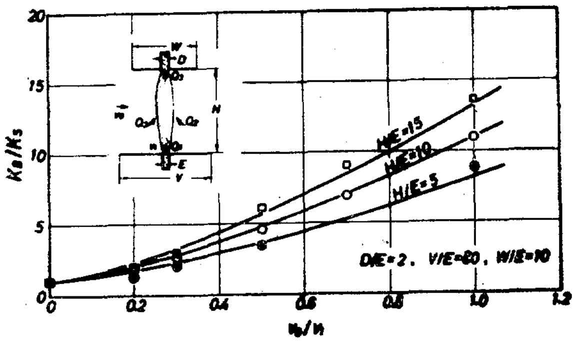


Fig. 4·5

Here, most important points are explained:

1) The values of W/E influence remarkably on the values of K_S, if the values are under 2.0. That is, it means that we must design at the values over 2.0, as Fig. 4·3 shows.

2) The values of K_S increase with the increase of the values of H/E and W/E as shown in Fig. 4·4.

3) The values of K_B/K_S increase with the increase of the values of v_0/v_1 and H/E as shown in Fig. 4·5.

4.2 Design method of push-pull hoods by "Flow Ratio Method"

Two dimensional push-pull hoods can be designed by using following equations.

$$Q_3=Q_1+Q_2=Q_1(1+K_D) \quad (4.1)$$

$$Q_{3L}=(Q_1+Q_2)_L=Q_1(1+K_B) \quad (4.2)$$

$$K_D=m \cdot K_B \quad (4.3)$$

$$K_B=K_S \cdot \{4(v_0/v_1)^{1.4}(H/E)^{0.5}(V/E)^{-0.05}+1\} \quad \% \quad (4.4)$$

$$K_S=(H/E)^{1.1}\{4.6(W/E)^{-1.1}+1.3\}\{0.4(V/E)^{0.2}+5.1\} \quad \% \quad (4.5)$$

where, $0.5 \leqq D/E \leqq 10.0$, $0 \leqq v_0/v_1 \leqq 1.0$

$1.4 \leqq V/E \leqq 80$, $m \geqq 1.0$

$2.0 \leqq W/E \leqq 50$, $3.0 \leqq H/E \leqq 30$

5. Practical Design of Ventilation and Dust Collecting System

(Example) 1

Fine dusts are being produced in a drier shown in Fig. 5·1 and are mixing with hot dried air Q_1 and air from surroundings Q_2; that is, the mixed air Q_3 shown in Fig. 5·2 is being exhausted from ducts.

Design local exhaust system as shown in Fig. 5·3 under the condition indicated in Table 5·1.

(A) Solution by "Flow Ratio Method"

1) Decision of hood's shape and size

Hood's shape is thought to be suitable as shown in Fig. 5·1, considering the shape of the source of contaminant and the setting up conditions; furthermore, the exshaust system becomes to be concise, if dual duct system is adopted as shown in the figure.

Table 5.1

Source of contaminant	Drier
Type of source	E=230 mmφ
	3
Condition of contaminated gas	Middle Safety Factor
	Q_1=0.51 m³/min
	v_1=0.2 m/s
	Δt=50°C
Condition for hood design	running always

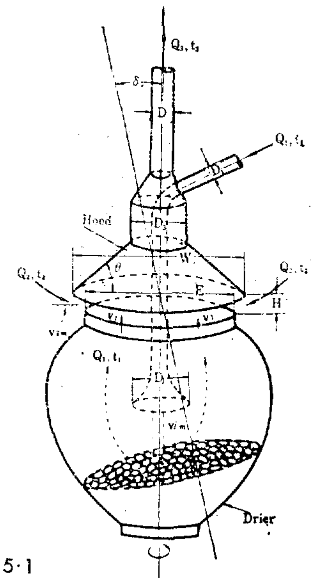


Fig. 5·1

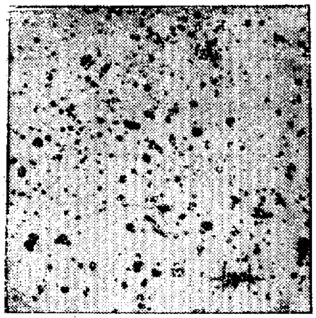


Fig. 5.2

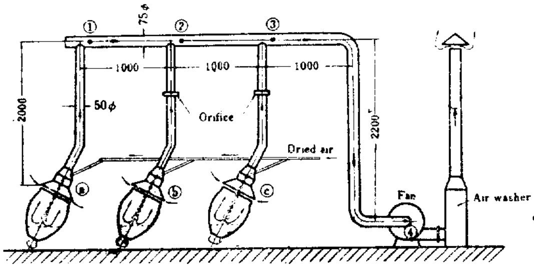


Fig. 5.3

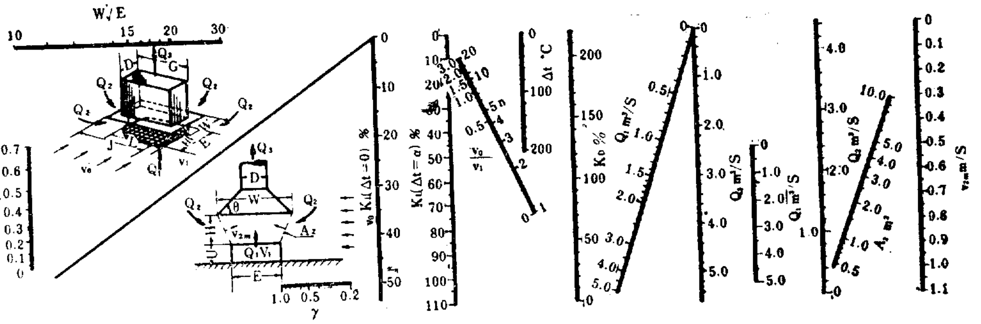


Fig. 5.4

Here, the size ratios are selected as follows considering the setting up conditions;

$\theta=30°$, $H/E=0.05$, $W/E=1.13$, $D_3/E=0.48$.

Therefore, we get the sizes of the system

$H=12$ mm, $W=260$ mm, $D_3=125$ mm

and

$D_i=38$ mm, $v_{im}=7.5$ m/s,

$D_j=150$ mm, $v_{jm}=0.48$ m/s. (See Fig. 5·1)

2) Decision of the value of Q_3

We get in order each value by using Fig. 5·4 or Eq(2.8) and Eq(2.12)

$K_{L(\Delta t=0)}=9$ %, $K_{L(\Delta t=50)}=14$ %

and adopting the value of n to be 10, we have

$K_D=140$ %, $Q_3=1.22$ m^3/min,

and have the following value from $A_2=0.064$ m^2, $v_{2m}=0.81$ m/s. Furthermore we have

$G_3=\gamma_1Q_1+\gamma_2Q_2=1.405$ kg/min.

Each value is summarized in Table 5.2, and the state of being exhausted is shown in Fig. 5.5.

3) Design of exhaust duct system (See Fig. 5.6)

Here, we have the following equations;

$$P_0=P_{④}+\frac{\gamma}{2g}v_{d③}^2+N\frac{\gamma}{2g}v_b^2+\zeta_{b①}\frac{\gamma}{2g}v_{d①}^2$$

$$+\lambda\frac{L}{D_d}\frac{\gamma}{2g}v_{d①}^2+\zeta_{d②}\frac{\gamma}{2g}v_{d②}^2$$

$$+\lambda\frac{L}{D_d}\frac{\gamma}{2g}v_{d②}^2+\zeta_{d③}\frac{\gamma}{2g}v_{d③}^2, \qquad (5.1)$$

$$P_0=P_{④}+\frac{\gamma}{2g}v_{d③}^2+(N+\Delta N_b)\frac{\gamma}{2g}v_b^2$$

$$+\zeta_{b②}\frac{\gamma}{2g}v_{d②}^2+\lambda\frac{L}{D_d}\frac{\gamma}{2g}v_{d②}^2+\zeta_{d③}\frac{\gamma}{2g}v_{d③}^2, \qquad (5.2)$$

$$P_0=P_{④}+\frac{\gamma}{2g}v_{d③}^2+(N+\Delta N_c)\frac{\gamma}{2g}v_b^2$$

$$+\zeta_{b③}\frac{\gamma}{2g}v_{d③}^2, \qquad (5.3)$$

where,

N: Coefficient of total resistance of branch duct

ΔN: Coefficient of orifice resistance

ζ: Coefficient of confluence

λ: Coefficient of pipe friction loss

L: Length between adjacent branches, m

v: Flow velocity, m/s

γ: Specific gravity, kg/m³

D: Pipe diameter, m

P: Static pressure, kg/m²

Suffix

①, ②, ③, ④: Position

d: Main duct

b: Branch duct

Table. 5·2

K_L	9%
n	10
K_D	140%
Q_3	1.22 m³/min
V_{2m}	0.81 m/s

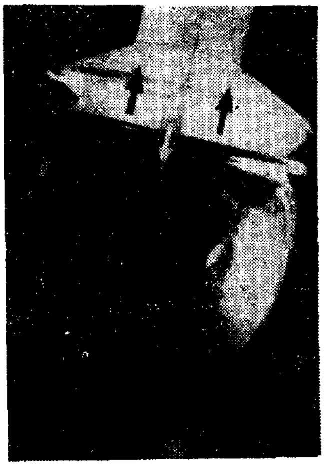


Fig. 5·5

Substituting each value into Eq. (5.1), Eq. (5.2) and Ed. (5.3), we get the value of ΔN_b and ΔN_c. Next, orifices diameter $D_{orⓑ}$, $D_{orⓒ}$ and orifice area ratios m_b, m_c. are obtained from the following Oki Equation

$$\zeta = \Delta N = \left(\frac{1}{m}-1\right)\left(\frac{2.75}{m}-1.56\right), \qquad (5.4)$$

and the results of calculations are shown in Table 5.3.

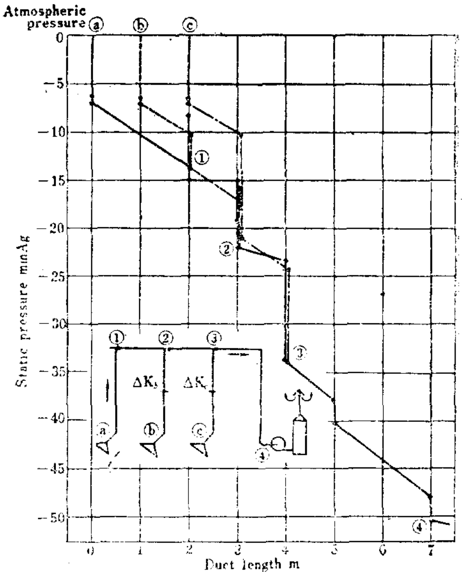


Fig. 5·6

Table. 5.3

ΔN_b	0.55
m_b	0.78
$Dor_{ⓑ}$	39.0 mm
ΔN_c	1.64
m_c	0.63
$Dor_{ⓒ}$	31.5 mm

Next, in the figure energy losses from each hood to the confluent point ③ are all equal and each value is

$$\Delta P_{ⓐ-③} \fallingdotseq 22 \text{ mmAq}. \qquad (5.5)$$

Energy loss from the point ③ to the fan entrance ④ is

$$\Delta P_{③-④} \fallingdotseq 16 \text{ mmAq}. \qquad (5.6)$$

Then, if energy loss after the fan is assumed to be 20 mmAq, fan capacity to be required is

$$\Delta P_{all} \fallingdotseq 60 \text{ mmAq}$$

$$Q = 3.6 \text{ m}^3/\text{min} \qquad (5.7)$$

By the way, static pressure distribution in the system becomes to be shown in Fig. 5.6.

(Example) 2

1) Decision of hood's shape and size

Push-Pull hood shown in Fig. 5.7 is suitable being considered the shape of the source of contaminant and the setting up conditions, By the way, in this case the relative size become as shown in Fig. 5.8; that is, $W'=3$ m, $D'=2$ m, $E'=2$ m, $H'=6$ m, $V'=2$ m, and $D/E=4/4=1.0$, $V/E=4/4=1.0$, $W/E=6/4=1.5$, $H/E=6/4=1.5$, $v_0/v_1=0.3/1=0.3$

Table. 5.4

Source of contaminant	Dust of HNH_3	Permit Density 10 mg/m^3
	Fume of Zn	Permit Density 15 mg/m^3
Type of source	$E=1.8$ m, $L=4.5$ m	
	Melted Zn temperature $t=450$°C	
	Air turblence 0.5 m/s	
Condition for design	Work from longer side and upper side	
	Air velocity on the surface of the source should be under 0.5 m/s	

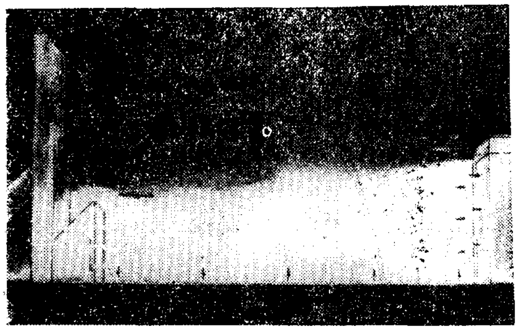


Fig. 5 · 9

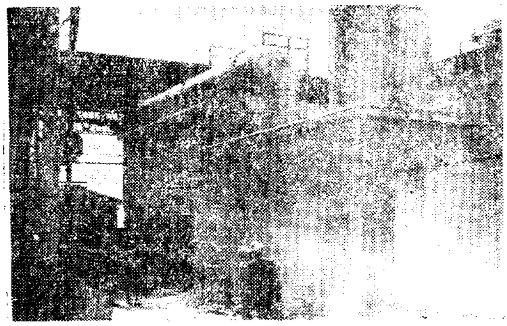


Fig. 5 · 10(c)

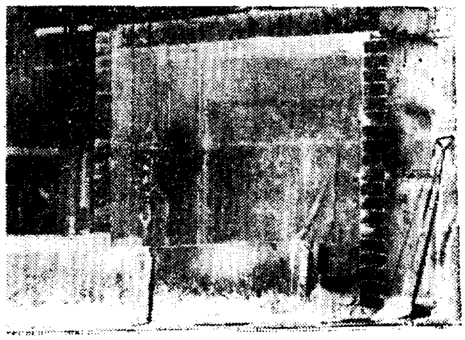


Fig. 5 · 10(a)

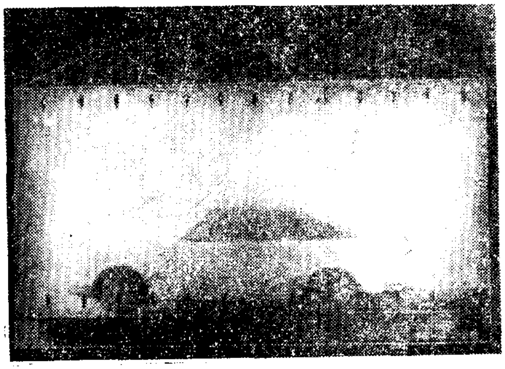


Fig. 5 · 11

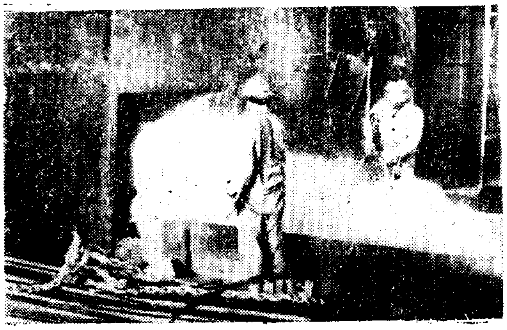


Fig. 5 · 10(b)

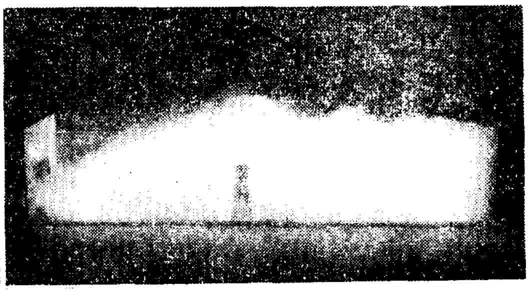


Fig. 5 · 12

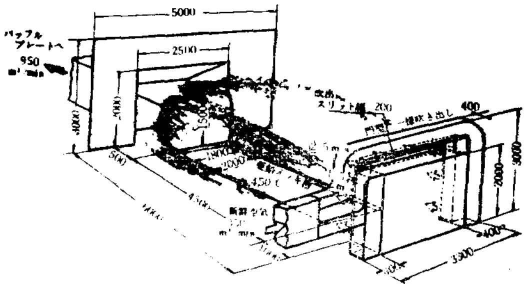


Fig. 5.7

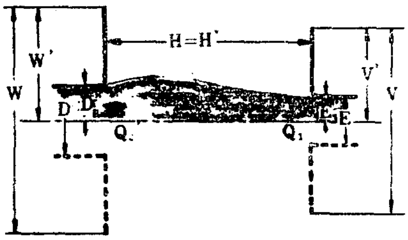


Fig. 5.8

2) Decision of the value of Q_3

Putting in these values in Eq. (4.1)~Eq. (4.5), we get

$K_S=1.5^{1.1}\times\{4.6/1.5^{1.1}+1.3\}\{0.4\times1\div5.1\}=37\ \%$

$K_B=37\{4\times0.3^{1.4}\times1.5^{0.5}\times1+1\}=72\ \%$

$K_D=72\times4\fallingdotseq300\ \%$

$Q_3=300(1+3)=1200\ m^3/min$

3) The results

Fig. 5·9 shows the air tunnel flow by a model of a push-pull hood, and Fig. 5·10(a), (b) are the push-pull hoods and (c) is the bag filter which is applied.

(Example) 3, 4

These are different types of push-pull hoods. (See Fig. 5·11 and Fig. 5·12)

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