PREDICTION OF CAPTURE EFFICIENCY OF KITCHEN EXHAUST SYSTEM
—— BUOYANT PLUME FROM GAS COOKING STOVE

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In order to design the kitchen exhaust system in a dwelling house, it is necessary to predict the capture efficiency of cooking hood for heat and pollutants from gas cooking stove.
We try to find a simplified method to predict the capture efficiency from characteristics of buoyant plume and exhaust flow into the hood.
To obtain basic data for the prediction, first of all, laboratory tests are carried out to simulate the characteristics of buoyant plume from gas cooking stove in free space without cross-draught. In the tests, the upward velocity, air temperature and concentration of carbon dioxide of plume above the gas stove are measured.
In result, it is confirmed that the distributions of the velocity, temperature and concentration are approximated to Gaussian profiles, and we can predict the velocities and temperatures in any positions of the buoyant plume by using some calculating charts obtained by measurements.

REFERENCES

1. C. J. Chen and W. Rodi, (1980), Vertical Turbulent Buoyant Jets — A Review of Experimental Data, HMT, the science applications of heat and mass transfer, vol.4, Pergamon Press, London
2. K. Nitta et al, (1976), Buoyant Plume from Flame, Summaries of Technical Papers of Annual Meeting Architectural Institute of Japan, 189-190

INTRODUCTION

When designing a kitchen exhaust system of dwelling house, it is necessary to predict the capture efficiency of cooking hood for heat and pollutants from gas cooking stove. The capture efficiency of a hood is defined as

$$\eta = \frac{G}{G_0} * 100 \quad (\%) \qquad (1)$$

where G_0 is the contaminant generation rate, G is the rate at which it is removed by the hood.

However, having specified a capture efficiency for any system, it is then necessary to relate this to the hood/velocity field parameters and the release parameters. In case of a kitchen exhaust system, the former would include the hood face area, the air volume flow rate into the hood, the center-line separation of the hood and gas stove, side walls condition surrounding the hood. And the latter would include calorific power of gas stove, shape and size of pan, side walls condition surrounding the gas stove. The first set of parameters control the exhaust flow into the hood, and the second set of parameters control the diffusions of the pollutants and heat at cooking. The objective of this study is to find a simplified method to predict the capture efficiency of a cooking hood from the two sets of parameters on practical level. If both of them are considered to have negligible effects on each other and the characteristics of buoyant plume and exhaust flow into hood are kept separate to hold, it is possible to accomplish the purpose by composing them with some simplified methods. To obtain the basic data for prediction, therefore, first of all, laboratory tests to simulate the characteristics of buoyant plume in free space without crossdraught are performed. From the results of tests, a method to predict the characteristics of buoyant plume from gas stove in a free space is suggested in this paper.

TEST RESULTS

Tests are carried out in a spacious laboratory. During the tests, cross-flow in the laboratory is negligible compared with buoyant plume. As is shown in Fig.1, when a pan with boiling water is being heated by a gas stove using city-gas 13A on the steady state, the upward air velocity, air temperature and concentration of carbon dioxide are measured at 147 points in total through 7 sections above the gas stove. As varied parameters, shown in Table.1, size of pan and calorific power of gas stove are took up.

Fig.2 shows the distributions of the excess air temperature over ambient air(ΔT) above the gas stove. The smaller the size of a pan and the larger the calorific power of a gas stove, the higher the air temperature above the pan becomes. On the other hand, we find that an extent of the plume from gas cooking stove, for example the contour of T=3℃, depends only on the heating power of the stove.

Table.1 Varied parameters and the generation rate of vapor from pan in the tests (kg/h)

calorific power of gas stove \ size of pan	16cm	20cm	24cm	28cm
high (8916kJ/h)	1.74	2.10	2.22	2.22
medium (4941kJ/h)	1.17	1.20	1.23	--
low (3063kJ/h)	0.69	0.69	0.78	--

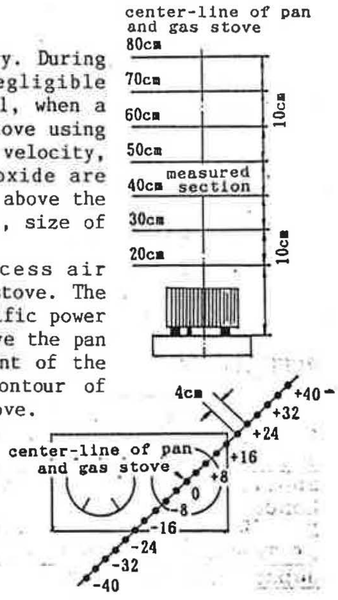

Fig.1 Positions of measured points

Fig.3 shows the distributions of upward air velocity (U) above gas stove. The stronger the heating power of a stove and the smaller the size of a pan, the larger the air velocity above the pan is. The position where the largest air velocity in a plume appears, however, also depends only on the heating power of stove.

The distributions of the excess concentration of carbon dioxide over ambient air(ΔC) are shown in Fig.4. These are very similar to the distributions of the temperature(ΔT) described above. In Fig.5, the vertical axis is non-dimensional excess concentration and temperature which are expressed by the ratios of ΔC and ΔT to their center-line values. Comparing the dimensionless concentration with temperature, we find that the curve of the distribution of ΔT is usually outside that of C. That is to say, the diffusion of heat is wider than that of gas contaminants. Hence, we can recommend that it is better to deal with the diffusion of heat in respect of safety when the characteristics of buoyant plume from gas cooking stove are discussed in order to design the exhaust system of kitchen.

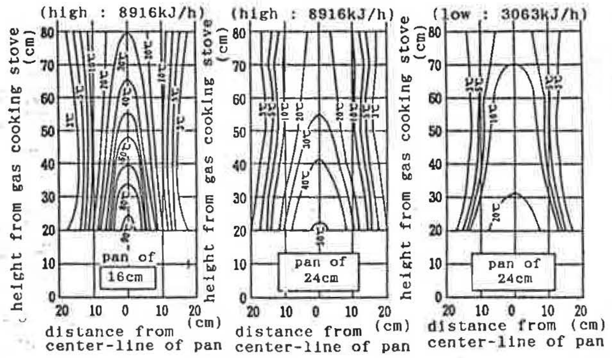

Fig.2 Distributions of excess temperature above gas stove

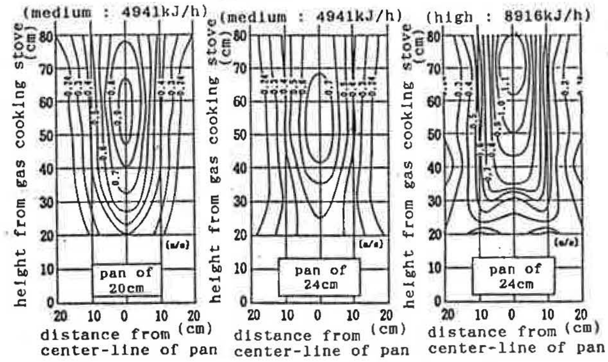

Fig.3 Distributions of upward velocity above gas stove

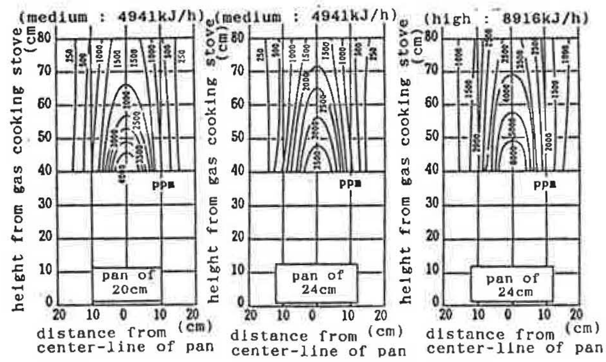

Fig.4 Distributions of concentration of carbon dioxide above gas stove

A MODEL OF BUOYANT PLUME FROM GAS COOKING STOVE

If the experimental data are presented in a dimensionless way, in which we choose the center-line velocity (U_c) as velocity scale, the center-line excess temperature (ΔT_c) as temperature scale, and a characteristic width b of the plume, for example the half-width $y_{0.5U}$ or $y_{0.5T}$ defined as follows, as length scale, the velocity and excess temperature distributions are approximated to Gaussian profiles, i.e. the

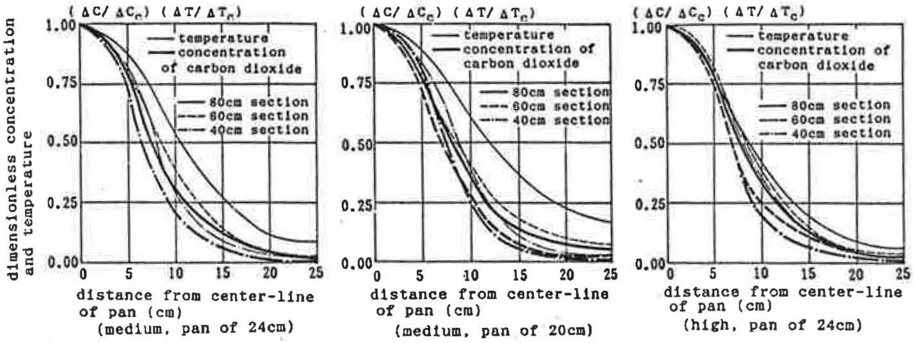

Fig.5 Comparisons between the dimensionless excess temperature and concentration of carbon dioxide

distributions can be written as

$$U(z,y)=U_c(z)\exp(-ky^2/b_u(z)^2) \qquad (2)$$

$$\Delta T(z,y)=\Delta T_c(z)\exp(-ky^2/b_t(z)^2) \qquad (3)$$

here, $k=\ln 2$

$\Delta T=T-T_a$, T_a: ambient air temperature

$b_u=y_{0.5U}$: value of y, at which air velocity U is half its center-line value

$b_t=y_{0.5T}$: value of y, at which excess temperature ΔT is half its center-line value

Fig.6 shows an example of dimensionless velocity distribution plotted against the dimensionless width. Except for the velocity at the height of 20cm and 30cm sections and in a range where dimensionless width is greater than 1.2, all experimental data are on a single curve which is expressed by Eq.2. The reason why much difference appears in the greater dimensionless width is that the anemometer used in measurements can not measure a velocity smaller than 0.2m/s, i.e. when a velocity value was smaller than 0.2m/s, the measured value was 0.2m/s in the tests. We consider, therefore, it is valid to express a velocity distribution above gas cooking stove with the equation (2).

Fig.7 shows the variation of dimensionless excess temperature with dimensionless width. As the same as velocity, except for the data at the height of 20cm and 30cm sections, all the experimental data of temperature

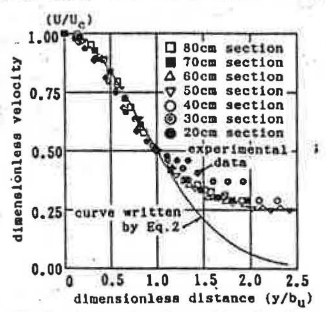

Fig.8 A example of the distribution of velocity above gas stove in dimensionless scale in the case of heating power of medium and pan of 24cm

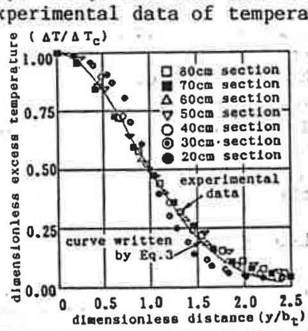

Fig.7 A example of distribution of excess temperature above gas stove in dimensionless scale in the case of heating power of high and pan of 24cm

are plotted on the curve expressed by Eq.3. Hence, we can say that equation (3) is valid for expressing a excess temperature distribution above gas cooking stove.

Knowing the distribution of upward velocity in any position, we can calculate a plume flux (Q) through any section which is at the same height or higher than of 40cm from gas stove with Eq.4. The plume flux is written as

$$Q(z)=\int_0^{b_e} U(z,y)2\pi y dy \qquad (4)$$

here, $b_e=b_u/\sqrt{\ln 2}$: value of y where velocity U becomes 1/e of its center-line value

On the other hand, in order to predict the upward velocity and excess temperature in any positions and to calculate the flux of plume through any sections with Eqs.2 to 4, it is necessary to know the center-line values of the velocity and temperature as well as their characteristic width b_u and b_t beforehand. Based on the experimental data, the variation of U_c, ΔT_c, b_u, b_t with the height from gas stove separation for different heating powers and sizes of pan are respectively described in Figs.8 to 11. From these figures, we don't think it is easy to write them with some functional equations about a height from gas stove, heating power of stove and size of pan as the case of buoyant plume from heated pad. Instead of functional equations, therefore, we consider it is possible to predict values of U_c, ΔT_c, b_u, b_t in any conditions by making calculation charts of them for different heights. Figs.12 to 15 are the examples of them at the height of 80cm from gas stove where a cooking hood is installed in general in Japan.

CONCLUSIONS

Laboratory tests on the characteristics of buoyant plume from a gas cooking stove in free space have shown that:

1. Above a gas cooking stove, the distribution of concentration of carbon dioxide is narrower than that of air temperature i.e. the diffusion of heat is wider than that of gas contaminants. When designing the exhaust system in kitchen, hence, it is better to deal with the diffusion of heat of the buoyant plume in respect of safety,
2. The distributions of upward velocity and excess temperature of buoyant plume above a gas cooking stove are approximated to Gaussian profiles. We can estimate the velocities and temperatures of plume in any positions with the equations (2) and (3) by obtaining U_c, ΔT_c, b_u, b_t from the calculating charts as is shown for example in Figs.12 to 15.

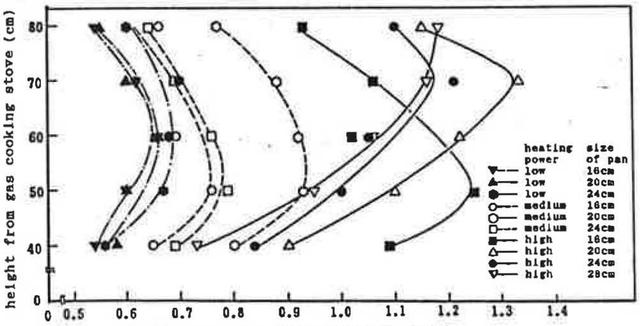

Fig.8 Variation of the velocity on center-line with the height from gas stove separation for different heating powers and sizes of pan

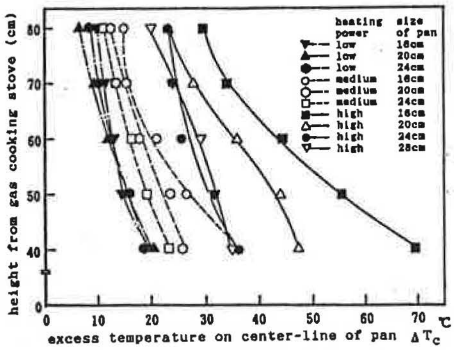

Fig.9 Variation of the excess temperature on center-line with the height from gas stove separation for different heating powers and sizes of pan

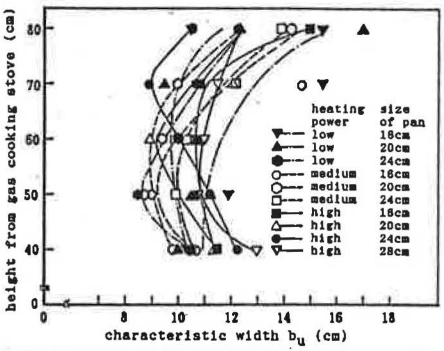

Fig.10 Variation of b_u with the height from gas stove separation for different heating powers and sizes of pan

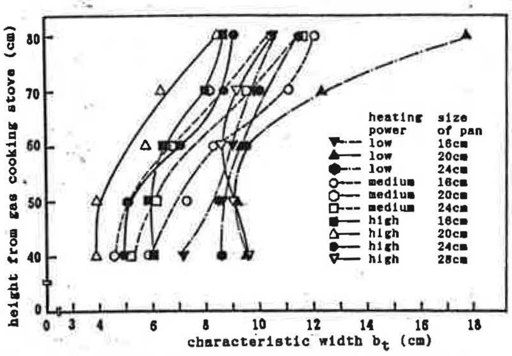

Fig.11 Variation of b_t with the height from gas stove separation for different heating powers and sizes of pan

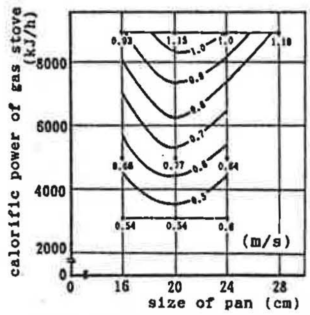

Fig.12 Calculation-chart of U_c at the height of 80cm

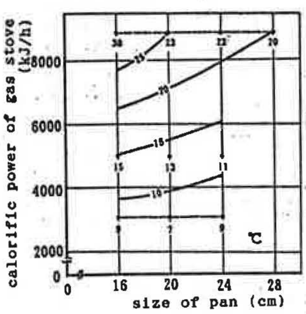

Fig.13 Calculation-chart of ΔT_c at the height of 80cm

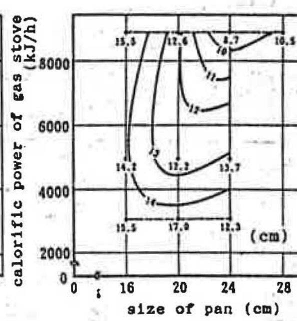

Fig.14 Calculation-chart of b_u at the height of 80cm

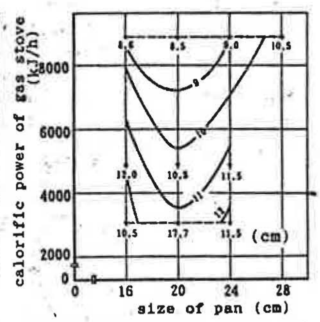

Fig.15 Calculation-chart of b_t at the height of 80cm