Researches on Ventilation of Underground Parking Places*[1]

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Abstract: When an underground parking place is not ventilated frequently enough, it is natural that the concentration of contaminated air cannot be lowered to less than the safety limit. Further, when the supply or exhaust air is not of laminar flow, the contaminated air concentration will increase locally due to stagnation of contaminated air or due to vorticies generated in that place, even with a sufficient number of times of ventilation per unit time.

In this connection, comparatively few reports about ventilation of underground parking places are found; and if any, most of them are directed to large-scale parking places. Therefore, the authors are going to offer a new simple designing formula applicable to underground parking places of any size and shape.

1. Conventional designs for ventilation

Several reports concerning ventilation of underground parking places are found [1)~3)], and examining their designing formulas, their basic concepts can be summerized as follows:

1) The "frequency of incoming and outgoing cars" is defined as the number of incoming and outgoing cars per unit time relative to the accommodation limit of the parking place, and the necessary unit space per parking car is previously fixed, although it is different depending on the reports.

2) Simplified calculation formulas are obtained either by supposing the mean driving time in minutes of the cars in the parking place, or by supposing the mean exhaust volume of CO per car.

3) In some of the reports, the mean value of CO exhaust is defined by the ratio of the number of cars with engines in operation to the number of all the parking cars in the parking place.

4) None of the calculation formulas do not take into account the concentration of contaminated open air.

As abovementioned, there are many inadequate points in the basic concepts of design, and they are as follows:

(a) A parking place usually includes a driver's waiting room, a fee-collecting booth, a car-washing room, a machine or electricity room and other service areas, which must actually be subtracted from the entire space of parking place. Thus, the accommodation capacities are not necessarily the same even if the entire areas of different parking places are the same. Therefore, it is considered inaccurate to employ the area of a parking place multiplied by the frequency of incoming and outgoing cars (the number of incoming and outgoing cars divided by the area of parking place) as the designing standard.

(b) Even when the number of incoming and outgoing cars per unit area per unit time, in one parking place is equal to that in another, the degree of internal air contamination differs depending on the scale of the parking places.

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*[1] This paper is translated from the following papers, J. Soc. Heat. Air-Cond. Sanit. Engr., J.SHASE, Vol. 48–2 (In Japanese) where more detailed expositions are found.

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That is, in small-scale parking place, the rate of time required for accelerating or decelerating cars is large compared with that in a steady driving state, and in a larger one, the relation is reversed. It does not seem reasonable, therefore, to reduce the formula by previously assuming the mean driving time or assumed exhaust volume of CO.

Besides, depending on the difference in the form of the parking places or car entering and leaving ways, the degree of air contamination and the number of required ventilation are variable even when the scales of parking places are the same or when the number of incoming or outgoing cars are the same.

(c) As for the idling, there are two cases.

In one case, the engine is working for the heating or cooling of the compartment of the parked car in winter or in summer; and, in the other, the engine is working for warming up, especially in winter.

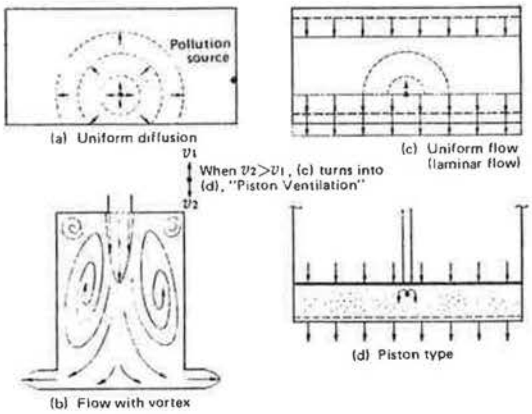

Fig. 1 Several patterns of diffusion and exhaust of polluted gas

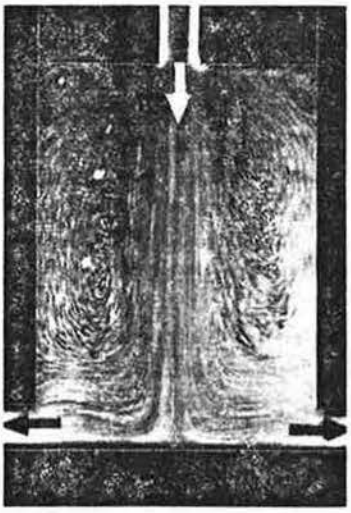

Fig. 2 Polluted gas doesn't diffuse uniformly because of generation of vortex

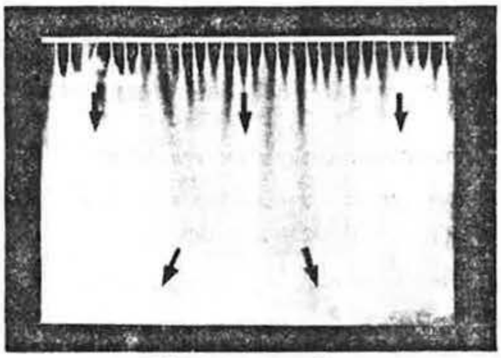

Fig. 3 Laminar Flow

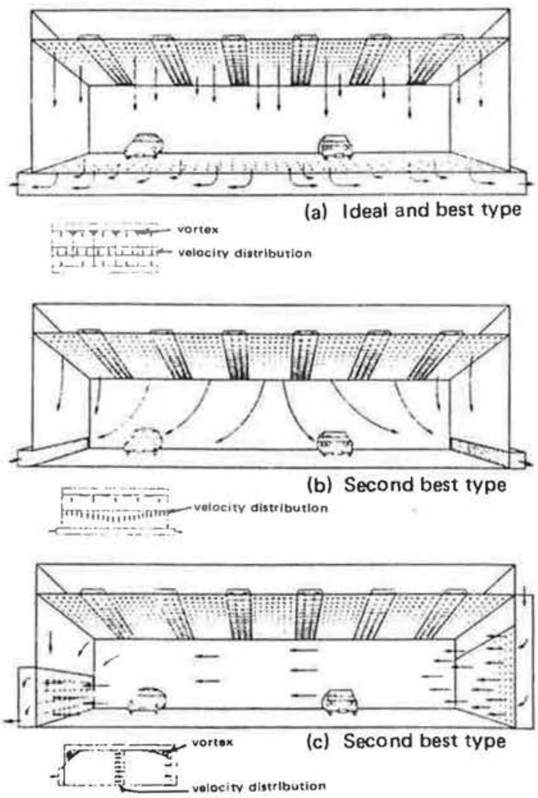

Fig. 4 Basic pattern of flow in parking places

Necessary time is different in these two cases. In the former, it is several minutes, and in the latter, it is ten minutes odd. So, it is not proper, to seek the average volume of exhaust, on the bases of the number of engine-working cars in parking places, but it is necessary to take the different volumes of exhaust into account.

(d) Under recent traffic circumstances, most of underground parking places located near crossing are supplied with fresh open air including exhaust gases of cars running on the ground. It is therefore necessary in such areas to prepare a ventilation plan taking into consideration the contamination of open air in designing a parking place.

2. Designing of underground parking place ventilation

2.1 Fundamental points of view about ventilation

In the first place, fundamental matters relating to ventilation will be shown.

1) Fig. 1 (a) shows how contaminated gas diffuses uniformly within a room with a certain velocity.

2) Fig. 1 (b) and Fig. 2 show sections of vortices induced in a room ventilated by a ventilation method which produces nonuniform diffusion of contaminated gas. (This phenomenon is usually observed in a working place ventilated by natural ventilation.)

3) Fig. 1 (c) and Fig. 3 show a "Push-Pull Type" ventilation method which utilizes laminar flow inducing uniform velocity distribution in a certain direction in a room.

4) Further, when $v_2 > v_1$ in Fig. 1 (c), "Piston Ventilation" is obtained as shown in Fig. 1 (d). In this case, contaminated gas is directly exhausted outside without diffusing inside. In short, in order to prevent occurrence of a vortex or stagnant flow inside a parking place, it is necessary to employ basic patterns of flow as shown in Figs. 4 (a)–4 (c); in these patterns, that shown in Fig. 4 (a) is the best, and those shown in Figs. 4 (b) and 4 (c) are the second best. In any way, these ventilating methods have already been adopted in some clean rooms in some manufacturing factories, and when properly designed, they can be put into practice relatively easily at low cost.

2.2 Mean concentration of CO in underground parking place employing dilution method

When the contaminated air concentration of underground parking place is defined as K, K is given generally by the following formula:

$$K=f(x,\ Q,\ V,\ N,\ L,\ v,\ M,\ K_o,\ K_i)$$

where,

- K : Mean CO concentration in parking place, m^3/m^3
- x : Number of incoming and outgoing cars per unit time, cars/h
- Q : Volume rate of ventilation, m^3/h
- V : Volume of parking place, m^3
- N : Number of times of ventilation ($=Q/V$), times/h
- L : Mean driving distance, m/car
- v : Mean driving speed, km/h·car
- M : Mean CO exhaust during driving, m^3/min·car
- K_0 : Concentration of supplied air, m^3/m^3
- K_i : Mean CO concentration in parking place due to idling, m^3/m^3

Here, it is natural that K is proportional to x or K_o, and inversely proportional to Q or N, but other effects of the other elements on K are very complicated.

Therefore, we shall make further discussions about these elements.

(1) Mean driving distance

As shown in Fig. 5, when dimensions of a parking place are defined by l, m and n, and a, b

and c are positive numbers (which are suitably selected taking into account the arrangement of exit, entrance and running route), the mean driving distance L of incoming and outgoing cars may be approximated as follows:

$$L=(al+bm+cn)$$

Patterns of several standard types of parking places and formulas of L are shown in Figs. 6 (a) – 6 (g).

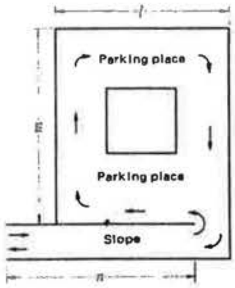

Fig. 5 Mean driving distance in parking place

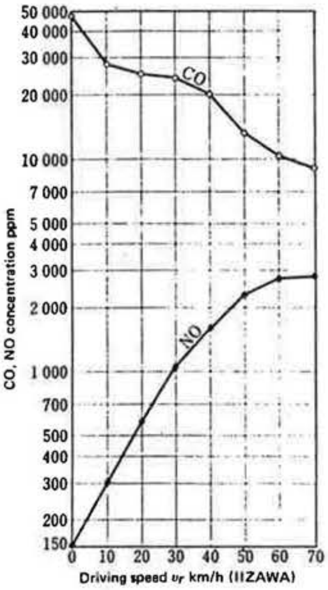

Fig. 7 Relation between exhaust concentration and driving speed

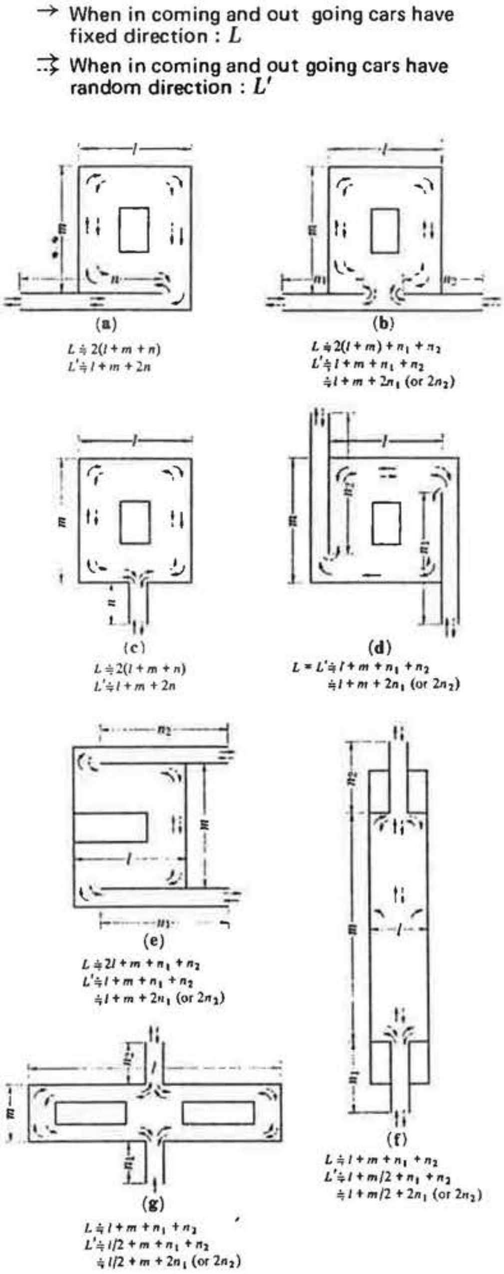

Fig. 6 Patterns of several standard parking places and methods to calculate L in each case

(2) Mean driving speed and volume of CO exhaust

The concentration of exhausted CO changes depending on the driving speed of the car, as apparent from the data shown in Fig. 7 [4] showing the mean value of those of gasoline cars, although it differs depending on the kind of cars, idling control, heating of air intake tube and type of carburetor.

In parking places where the driving speed is restricted to a relatively low value, the concentration of CO is generally taken as a factor which determines the cleanness of the environment. This condition is also adopted in this report.

According to the results of measurement by us or other references[5)~7)], the mean volume of exhaust gas is about 1.0 m^3/min in large parking place, and 1.5 m^3/min. in small ones; and CO gas volume is proportional to this volume.

As a matter of course, the driving speed is high in large parking places and low in small parking places. When no data of measurements are available, reference may be made to Table 1 and Fig. 8 showing the results based on the author's measurements.

(3) Mean CO concentration in parking place

Suppose that uniform diffusion of exhaust gas of car occurs in a parking place, and that there are no idling cars in the parking place, and the concentration of supplied air is zero, then the mean CO concentration will be given by the following equation, in which a constant 0.06 is used to adjust the unit:

$$K=\frac{0.06xML}{vQ} \quad \cdots\cdots (2.1)$$

where,

- K : Mean CO concentration in parking place, m^3/m^3
- x : Number of incoming and outgoing cars per unit time, cars/h
- M : Mean CO exhaust volume during driving, m^3/min·car
- L : Mean driving distance, m/car
- v : Mean driving speed, km/h·car
- Q : Ventilating amount, m^3/h

An example of calculation by Eq. (2.1) is shown in Fig. 9. In Fig. 9, the horizontal axis shows the rate of increase with time of the contaminated air concentration in the parking place, V is the volume (capacity) of the parking place, the designed concentration K_D (m^3/m^3) is taken as the parameter, and the vertical axis shows the number of times of ventilation N (=Q/V times/h).

Table 1 Relation between area of parking places and mean driving speed:

Area of parking place A m^2	Mean driving speed v km/h
500 under	5
1000 ~ 1500	10
2000 above	15

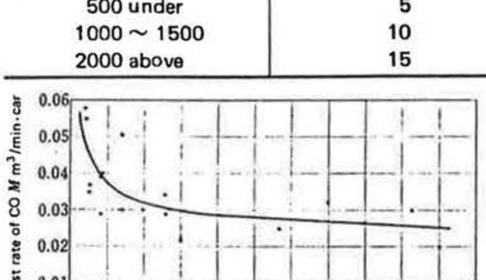

Fig. 8 Relation between area of parking place and mean exhaust rate of CO

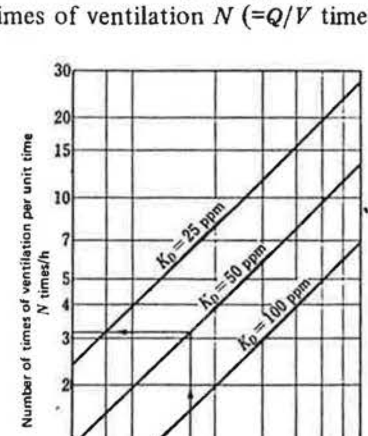

Fig. 9 Results of calculation using Eq. (2.1)

As shown by the arrow in Fig. 9, it will be understood that the value shown on the vertical axis is the necessary number of ventilations to obtain the expected mean CO concentration given by calculation of the formula shown on the horizontal axis.

2.3 Supplied air (Open air)

CO concentration of supplied air should be naturally added to Eq. (2.1).

Fig. 10 shows the values obtained in the author's measurements based on "Detective Tube Method" and carried out around open air introducing holes of ten buildings associated with underground parking places in Osaka.

From this figure it is found that the higher the position of the air introducing holes, (as on the top of the building), the lower is the value of CO concentration and that the value of CO concentration has no relation to the height when the wind velocity is over 3 m/s.

Besides, at smoggy time, the value of 20 ppm which was equal to the value on the ground was actually measured at the height of 40 m above the ground.

2.4 Mean concentration of CO during idling

Mean concentration of CO during idling is given by the following equation:

$$K_i = \frac{x_i\ t_i\ M_i}{Q} \qquad \cdots\cdots (2.2)$$

where,

K_i : Mean CO concentration due to idling in parking place, m^3/m^3

x_i : Number of cars idling per unit time, cars/h

t_i : Mean time of idling, min/car

M_i : Mean CO exhaust during idling, m^3/min·car

Q : Ventilating amount, m^3/h

Naturally, in winter, heating of parking places is preferable in that correspondingly less idling time is required thereby effectively preventing the pollution.

Accordingly to the measurement on the velocity of exhaust gas from exhaust tubes of several idling cars, the mean value of 2 m/s was obtained (revolution; 1500–2000 rpm), and the volume of exhaust gas from exhaust tubes of average diameter of 4 cm was 0.15 m^3/min. (In several reports, this value is 0.2 m^3/min)[5)~7)].

Accordingly, when the CO concentration in the exhaust is assumed to be 5% from Fig. 7 and due consideration is given for safety, the mean exhaust amount of CO during idling may be defined as M_i=0.01 m^3/min.

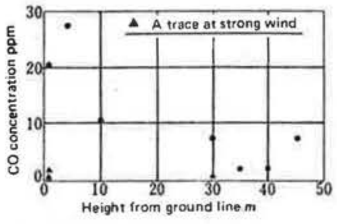

Fig. 10 Relation between pollution rate of supplied air and height of open air introducing opening

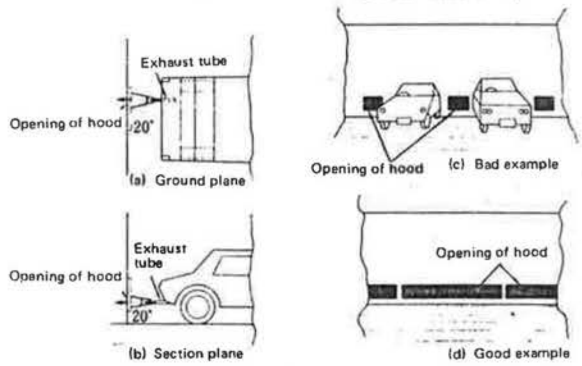

Fig. 11 Relative situation between exhaust tubes and openings of hood

2.5 Idling exhaust opening

Idling exhaust opening is the name given to a pull-type hood provided for rapid exhaustion to outside the parking place before the waste gas from the exhaust tube of cars diffuses within the room.

The relative positions of the outlet of an exhaust tube and a hood should correspond with each other as shown in Figs. 11 (a) and 11 (b), but actually they are frequently staggered as shown in Fig. 11 (c).

Therefore, continuous exhaust openings as shown in Fig. 11 (d), must be provided so that the exhaust tubes can be opposed always by the exhaust openings.

2.6 Required ventilation frequency

The number of times of ventilation N (times/h) is expressed by $N=Q/V$. Thus, when we define the design concentration of CO gas K_D (m^3/m^3) and supplied air concentration as K_0 (m^3/m^3), the following equation is obtained from Eqs. (2.1) and (2.2):

$$N=\frac{0.06MxL/v+x_i t_i M_i}{(K_D-K_0)V} \qquad \cdots\cdots (2.3)$$

It is desirable in the application of this equation to adopt "Piston Type Ventilation" with "Laminar Flow" which prevents the contaminated gas from diffusing within the room, but, as it is difficult to adopt such an ideal design practically, the following equation including a safety factor n is suggested:

$$N=\frac{n(0.06MxL/v+x_i t_i M_i)}{(K_D-K_0)V} \qquad \cdots\cdots (2.4)$$

where,

n : Safety factor for ventilation ($\geqq 1$), non-dimensional

Summary

1) Even when the numbers of incoming and outgoing cars per unit area are the same in parking places, the difference in the driving speed due to the difference of scale of the parking places results in different exhaust gas volumes.

Furthermore, even when the scales of the parking places are the same, the difference in the shape of the parking places or in the route of incoming or outgoing cars results in different exhaust gas volumes.

2) The degree of pollution is different between winter and other seasons.

3) In areas where open air conditions are bad, the concentration of the open air must be taken into consideration.

4) The presence of a vortex or stagnant air makes the concentration of polluted air higher locally.

5) "Piston Type Ventilation with Laminar Flow" will be the most effective and the best.

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