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Short Communication

Gaseous Contaminant Distribution in the Breathing Zone

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Abstract: Conventionally, the "breathing zone" is defined as the zone within a 0.3 m (or 10 inches) radius of a worker's nose and mouth, and it has been generally assumed that a contaminant in the breathing zone is homogeneous and its concentration is equivalent to the concentration inhaled by the worker. However, several studies have mentioned that the concentration is not uniform in the breathing zone when a worker is close to the contaminant source. In order to examine the spatial variability of contaminant concentrations in a worker's breathing zone, comparative measurements of personal exposure were carried out in a laboratory. In experiment, ethanol vapor was released in front of a model worker (human subject and mockup mannequin) and the vapor concentrations were measured at two different sampling points, at the nose and at the chest, in the breathing zone. Then, the effects of the sampling location and the body temperature on the exposure were observed. The ratios of nose concentration to chest concentration for the human subject and the mannequin were 0–0.2 and 0.12, respectively. The exposure level of the mannequin was about 5.5–9.3 times higher than that of the human subject.

Key words: Breathing zone, Exposure, Personal sampling

Conventionally, the "breathing zone" is defined as the zone within a 0.3 m (or 10 inches) radius of a worker's nose and mouth[1)]. It has been generally assumed that an airborne contaminant in the breathing zone is uniformly mixed and its concentration is equivalent to the concentration inhaled by the worker. Therefore, the concentration is deemed to be constant as long as it is sampled in the breathing zone. However, some doubts have been raised about this assumption. Several studies have mentioned that the concentration in the breathing zone can vary when the worker is close to the contaminant source[2–6)]. Bull *et al*.[2)] showed that test aerosol concentrations at the upper parts of the body tend to be higher than the concentrations at the lower parts. Malek *et al*. conducted a field investigation and found that styrene concentrations detected at a worker's nose were significantly different from the concentrations detected at the worker's lapels[3)]. Guffey *et al*. used a 60%-sized mannequin in a wind tunnel, and reported that the tracer gas concentration at the chest averaged about 2.9 times the concentration at the nose[4)]. Vinson *et al*.[5)] and Liden *et al*. reported the heterogeneous distribution of dust concentrations in the breathing zone[6)]. Based on these previous studies, the author aimed to evaluate the gaseous contaminant exposure of a stationary worker in a controlled laboratory atmosphere. In this study, measurements of personal exposure to organic solvent vapor were carried out to examine the spatial variability of the concentrations in the breathing zone.

Organic solvent handling by a sole standing worker was simulated. The main experiments of this study were carried out from March to April of 2011 in a "calm" laboratory. The average room temperature of the laboratory

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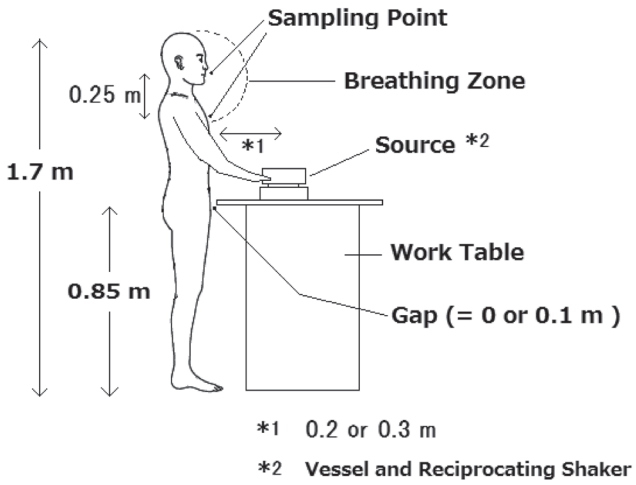

Fig. 1. Source location and sampling points in the experiment.

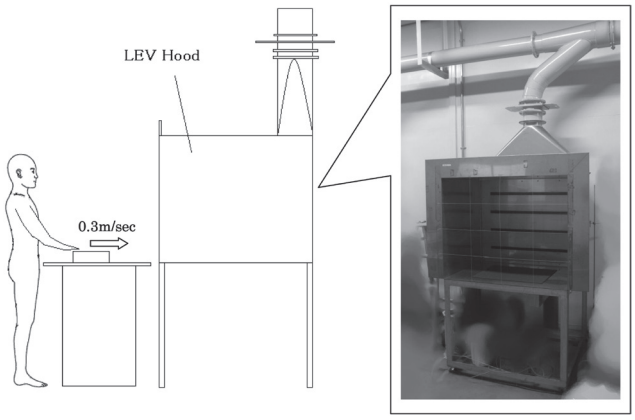

Fig. 2. Source location and LEV hood in the experiment.

during this period was about 12 °C. The term "calm" used throughout this paper refers to a condition without external wind as compared to the previous field and wind tunnel studies[2–6]. Ethanol was used as a representative organic solvent.

As shown in Fig. 1, a reciprocating steel vessel (440 cm^2 opening) containing about 40 ml ethanol was placed on a work table, and ethanol vapor was released from the vessel to the surrounding air at the rate of 0.16 g/min. The work table was located in front of the model worker. A 170 cm human subject and a mock up mannequin were employed as the model worker. The influence of natural convective flow due to body temperature on exposure was observed by comparing the human and the mannequin. The gap between the work table and the model worker was set at 0 m or 0.1 m. The ethanol concentration was monitored with a catalytic combustion type, high sensitivity gas monitor (XP-3160; New Cosmos Electric Co. Ltd.), for 5 min at two sampling points in the breathing zone: at the nose and at the chest of the model worker. Concentration data were recorded as 5 min TWA over the sampling time and are presented as the arithmetic means of ten repeated tests. The velocity of the upward convective flow in the human subject's breathing zone was measured by a portable multi-function thermal anemometer (Climomaster Model 6521; Kanomax Japan, INC.) which automatically displays the average velocity of ten measurements.

Besides, as shown in Fig. 2, an additional experiment was performed in conjunction with a local exhaust ventilation (LEV) system. It is known that the exhaust air current of a LEV often creates a wake[7] which can cause accidental exposure. In order to examine the combined effect of body heat convection and LEV wake, the human subject was placed in front of the LEV hood and the ethanol exposures were measured in the presence of the exhaust air current. The LEV hood opening was 1.0 m (W)×0.8 m (H) in dimension and the capture velocity of the LEV measured at the ethanol source point was set at 0.3 m/s. Although ethanol vapor was released from the same reciprocating vessel described above, it was released at the rate of 1.56 g/min in this experiment because the exhaust air current of the LEV enhanced the ethanol evaporation.

First, the average velocity of the upward convective flow due to body temperature was measured. It was measured at the chest of the human subject and was shown to be 0.2 m/s on average which might be comparable to typical wind speeds in common indoor workplaces[8].

Table 1 shows the ethanol concentrations measured in the breathing zone of the human subject and the mannequin. Each measurement was performed after at least 5 min interval.

As shown in the Table, the effect of the sampling location on the exposure was verified. Without the LEV, the nose concentrations were lower than the chest concentrations, and the differences were statistically significant ($p<0.05$). The ratios of nose concentration to chest concentration of the human subject and the mannequin were 0–0.2 and 0.12, respectively. These results are in agreement with those of other researchers who showed lower concentrations at nose/mouth level.

When the human subject stood in front of the LEV, ethanol vapor could be detected at neither the nose nor the chest in spite of the higher evaporation. Although it has been suggested that body heat convection would strengthen the wake and transportation of contaminant into the breathing zone[7], this phenomenon was not observed in

Table 1. Ethanol concentrations in the breathing zone

Model Worker	LEV	Gap (m)	Ethanol concentration (ppm) *	
			Chest	Nose
Human	–	0	**20** ± 17	**4** ± 6
	–	0.1	**4** ± 11	**0** ± 0
	ON	0	**0** ± 0	**0** ± 0
Mannequin	–	0	**185** ± 70	**22** ± 19

* Values are mean ± SD (n=10).

the present study, possibly due to the fact that the exhaust air current around the human subject was insufficient to form an obvious wake.

Contrary to the results of earlier studies, the exposure levels of the mannequin were 5.5–9.3 times higher than those of the human subject in this study. Dai *et al*. mentioned that the upward current resulting from human body heat would convey contaminant into the breathing zone[9], and Schmees *et al*. found that the effect of body temperature on exposure was minimal[10]. A definitive explanation for this discrepancy between the results of the present study and those of former studies is difficult, but the hypothesis of Welling *et al.* that uncontaminated air would rise with convection resulting from body heat and dilute contaminated air in the breathing zone is suggestive.

The effect of a small gap between the human subject and the work table on the exposure was experimentally confirmed. With a 0.1 m gap, the ethanol concentration at chest was reduced to 20% and the reduction was statistically significant ($p<0.05$). This is likely due to the fact that uncontaminated air below the table was ascended by body temperature through the gap, as described by Welling's hypothesis noted above. Therefore, exposure can successfully be reduced by ensuring a small gap between a worker and a work table in a calm condition. The ethanol concentration at nose level was also reduced by the gap; however the reduction was not statistically significant.

The results of this study lead to the following three conclusions. (1) The conventional concept of a breathing zone is unsuitable for some workers who handle organic solvents in calm air, and the personal samplers for these workers should be located within 5–10 cm from the worker's nose or/and mouth. (2) A simple mannequin may not be an appropriate surrogate for a human worker in exposure measurement studies, since the body temperature of a human seems to affect vapor contaminant inflow into the breathing zone. (3) Keeping about 10 cm distance from the work table may be beneficial for reducing vapor exposure in a calm condition.

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