Estimation of Formaldehyde Emissions in Pathology Laboratories: Measurement During Actual Work and Verification by CFD

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Abstract

During a pathological examination, formaldehyde is emitted into the work environment from formalin-fixed specimens. To develop an effective ventilation system that minimizes worker exposure to formaldehyde, it is necessary to estimate the quantity of formaldehyde emitted during work. However, calculating the formaldehyde emission theoretically poses challenges. In this study, we conducted measurements of indoor formaldehyde concentration in a pathology laboratory during actual work and estimated the emission rate per each work point. The results showed an average emission rate of 160 mg/h of formaldehyde per work point. Furthermore, Computational Fluid Dynamics (CFD) was employed to analyze the concentration distribution in the pathology laboratory based on the estimated emission rate. The CFD analysis indicated a slightly greater variation in concentration distribution compared to the actual measurements. In conclusion, this estimated emission rate can serve as a design parameter for ventilation systems and risk assessment in pathological laboratories.

1. Introduction

Pathological examinations are conducted in medical institutions to diagnose diseases and investigate their causes. During these examinations, organs and tissues are fixed with formalin, therefore formaldehyde is emitted from the specimens during and after the fixation process. Workers involved in pathology examinations are exposed to formaldehyde, which poses an increased health risk[1)]. Although there are safer alternatives, such as alcohol-based fixatives, to replace formalin as a fixative for tissues[2)], they have not gained mainstream acceptance for various reasons. To avoid workers from formaldehyde exposure, it is crucial to minimize the dispersion of formaldehyde into the work environment. Local exhaust ventilation equipment, such as fume hoods and push-pull ventilation systems, are commonly employed to prevent chemical exposure. Additionally, specific measures aimed at formaldehyde, such as the development of a dissecting bed with local exhaust for an anatomy laboratory, have been implemented. In pathology laboratories, push-pull ventilation systems are preferred as they facilitate collaboration between pathologists and histotechnologists during the dissection process. However, it has been observed that a significant number of pathology laboratories still lack local exhaust ventilation equipment, and several reports have indicated that formaldehyde concentrations exceed recommended limits in such laboratories, even when local exhaust ventilation equipment was installed[3-5)].

To design pathology laboratories that are safe, it is not sufficient to solely install local exhaust equipment. It is crucial to implement comprehensive ventilation systems for the entire room, taking into account the quantity of emitted formaldehyde. In the field of occupational health, numerous models have been developed to estimate the volatilization and evaporation rates of organic solvents[6, 7)]. However, these models make the assumption of pure substances, which presents a challenge in accurately estimating the quantity of formalin emissions due to its complex composition. Additionally, the models assume a simplistic liquid surface as the emission source, but the geometry of the specimen treated in pathology laboratories is much more complex.

In anatomy laboratories, similar to pathology laboratories, formalin is utilized for the preservation of cadavers. Toda et al.[8)] conducted measurements of formaldehyde concentration in anatomy laboratories during dissection activities performed by medical students and estimated the quantity of formaldehyde emitted per cadaver. However, there exist notable distinctions between anatomy laboratories and pathology laboratories. For instance, anatomy practice involves sectioning of whole bodies, whereas in pathological examinations, specimens are dissected into smaller fragments. Consequently, the estimated amount of formaldehyde emission in the anatomy laboratory does not apply to the design of ventilation equipment in pathology

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laboratories.

In this study, our objectives were to acquire fundamental data for ventilation design and risk assessment in pathology laboratories. To achieve this study, we conducted measurements of formaldehyde concentration within an operational pathology laboratory and estimated the emission rate of formaldehyde per work point. Moreover, in order to validate the estimated amount of formaldehyde emission, we conducted computational fluid dynamics (CFD) analysis to assess the reproducibility of the concentration distribution of formaldehyde within the pathology laboratory.

2. Methods

2.1 Sampling of an actual pathology laboratory and estimation of formaldehyde emission rate

To estimate the quantity of formaldehyde emitted during actual work, we conducted two measurements of formaldehyde concentration in a pathology laboratory during working hours. The pathology laboratory was located in a specific hospital in Tokyo and had a floor area of approximately 99 m^2, with a ceiling height of 2.7 m. The laboratory's floor plan, location of fixtures, work points and measurement points are depicted in Figure 1. The layout plan indicating the locations of the air vents is presented in Figure 2, while Table 1 provides detailed information about each air vent. The main activity during the measurement period was dissection, performed on the central cutting table within the laboratory. The sink cabinet, situated in the upper left corner of Figure 1 and Figure 2, was equipped with a local exhaust inlet; however, no work was conducted at the sink cabinet during the measurement period. The total ventilation air volume for the entire room, encompassing both local and general ventilation, was 3,000 m^3/h. To determine the average concentration within the laboratory, sampling was conducted at five points positioned at a height of 1.5 m above the floor. The determination of these sampling points followed the Japanese working environment measurement protocol. The sampling duration was set at 10 minutes, with a sampling flow rate of 1.5 L/min, resulting in a sampling volume of 15 L. Formaldehyde concentration was quantified using the 2,4-dinitrophenylhydrazine solid-phase adsorption - solvent extraction - high-performance liquid chromatography (DNPH-HPLC) method.

Based on the assumption that formaldehyde is emitted solely from work points, the total quantity of formaldehyde emitted throughout the entire pathology laboratory can be calculated by multiplying the number of work points by the average formaldehyde emission rate per work point. The total amount of formaldehyde emission is also calculated by multiplying the difference between the indoor formaldehyde concentration and the outdoor formaldehyde concentration by the ventilation volume. Therefore, the total amount of formaldehyde emission can be determined as follows:

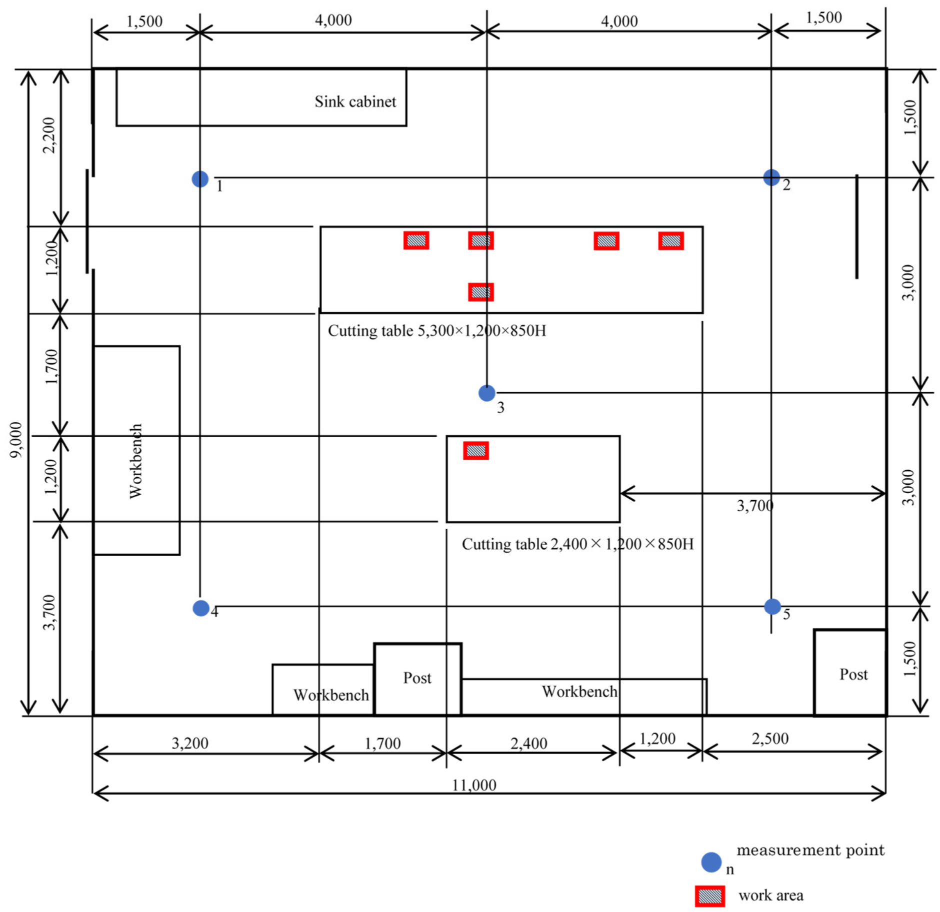

Figure 1 The floor plan of the laboratory, the fixtures and work areas, the locations of the measurement points

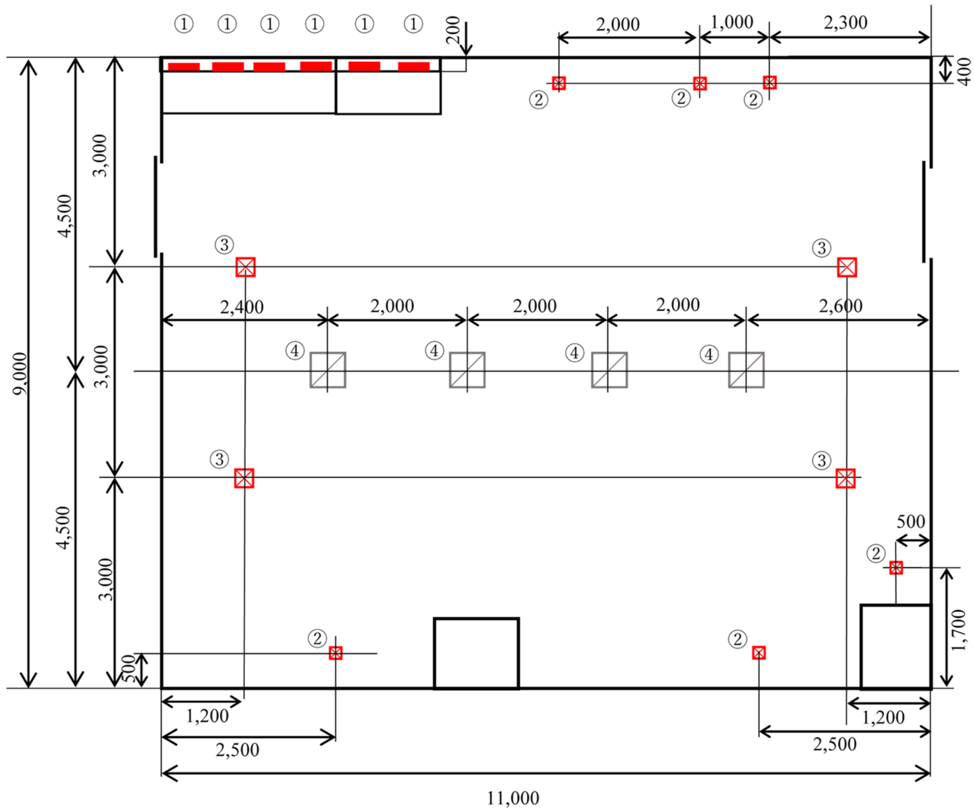

Figure 2 The layout plan of air vent locations

Table 1 Details of each air vent

Symbol in Figure 2	Type	Number of openings	Size [mm]	Installation height [mm] and location	Each air volume [m^3/h]
①	Local exhaust grille	6	450W×100H	FL+850 (bottom end) on the sink cabinet	50
②	Exhaust grille	6	200W×200D	FL+300 on the ceiling	150
③	Exhaust grille	4	250W×250D	FL+2,700 on the ceiling	460
④	Supply air diffuser	4	250W×250D	FL+2,700 on the ceiling	760

$$n \cdot ER = Q_v \cdot (C_{indoor} - C_{outdoor}) \cdot 10^{-3} \quad (1)$$

where n is the number of work areas, ER is the emission rate per work area (mg/h), Q_v is the ventilation air volume (m^3/h), C_{indoor} is the formaldehyde concentration in the pathology laboratory (μg/m^3), and $C_{outdoor}$ is the formaldehyde concentration in air supplied from outside the pathology laboratory (μg/m^3). In this study, the arithmetic mean of the formaldehyde concentration obtained at each measurement point was calculated as the value of C_{indoor}. Considering that the formaldehyde concentration in air supplied from outside the pathology laboratory is much lower than in C_{indoor}, $C_{outdoor}$ was set at 0 μg/m^3. By applying these assumptions, the average emission rate per work point was calculated.

2.2 Validation of concentration distribution through Computational Fluid Dynamics (CFD) analysis

In the previous section, we mentioned that the arithmetic mean value of the formaldehyde concentration at each measurement point is used as the average concentration within the pathology laboratory. However, in reality, formaldehyde does not disperse uniformly instantaneously. Consequently, the estimation method employed in the previous section may not accurately estimate the formaldehyde emission. In order to verify the estimated formaldehyde emission rate, we developed a computer model that simulated the pathology laboratory and sought to reproduce the concentration distribution using the formaldehyde emission rate obtained in the previous section. A summary of the CFD parameters is presented in Table 2. The model did not account for the temperature effects of air conditioning, and the initial temperatures of the building frame and air outlets were set to 26°C. Moreover, no model representing the human body was incorporated.

3. Results and Discussions

Table 3 shows the formaldehyde concentrations obtained from actual measurements and CFD analysis at each measurement point. Table 4 shows the average concentrations in the pathology laboratory, the estimated total emissions, and the estimated emissions per work point obtained from two actual measurements. During the measurement period, most of the work was conducted in the upper section of Figure 1, suggesting that concentrations at measurement points 1 to 3, located closer to the work area, would be higher. However, contrary to expectations, there was not a significant difference compared to measurement points 4 and 5. This observation indicates that the formaldehyde emitted from the work points diffused throughout the pathology laboratory. The estimated formaldehyde emissions per work point obtained from two measurements were 140 mg/h and 185 mg/h, respectively, with an average of 162.5 mg/h.

CFD analysis was performed using the estimated emission rate per work point of approximately 160 mg/h, which was obtained from the actual measurements. The formaldehyde emission sources were modeled as rectangular parallelepipeds with dimensions of 300 mm (width), 200 mm (depth), and 20 mm (height), uniformly generating formaldehyde at a rate of 3.7×10^{-5} kg/m^3・s formaldehyde uniformly. The concentration near the emission source did not reach a fully steady state in the calculated results. However, the concentration far from the emission source stabilized after several thousand cycles. Figure 3 represents the contour plot of formaldehyde concentration at a cross-section with a height of 1.5 m, obtained at the 10,000th cycle through CFD analysis. It can be observed from Figure 3 and the standard deviation values shown in Table 2 that the concentration distribution obtained through CFD analysis exhibits greater variability compared to the results of actual measurements. The CFD model does not incorporate temperature differences arising from the air conditioning system, nor does it account for the effects of heat generation and movement by workers. In the actual measurements, the air was agitated due to the supplied air is temperature regulated and differs from the room temperature. Additionally, the movement of workers and the heat generated by both workers and equipment contributed to air agitation.

Table 2 CFD analysis conditions

Software	STREAM Ver 12
Finite-difference schemes	QUICK
Analysis method	Steady state analysis
Turbulence model	Standard k-ε
Analysis area	1.1 × 0.9 × 2.7 [m]
Mesh	x138 × y87 × z39 = 468,234
Diffusivity	1.517×10^{-5} m^2/s (Formaldehyde in air)

Table 3 The formaldehyde concentrations at each measurement point

Measurement point	Formaldehyde concentration [μg/m^3]		
	1st measurement	2nd measurement	CFD
1	310	370	340
2	320	490	630
3	290	380	917
4	250	260	166
5	250	370	227
arithmetic average (SD)	280 (29)	370 (73)	456 (280)

Table 4 Average concentrations, the estimated total emissions and the estimated emissions per work point

	Average concentration [μg/m^3]	Estimated total emission [mg/h]	Estimated emission per work area [mg/h]
1st measurement	280	840	140
2nd measurement	370	1,110	185

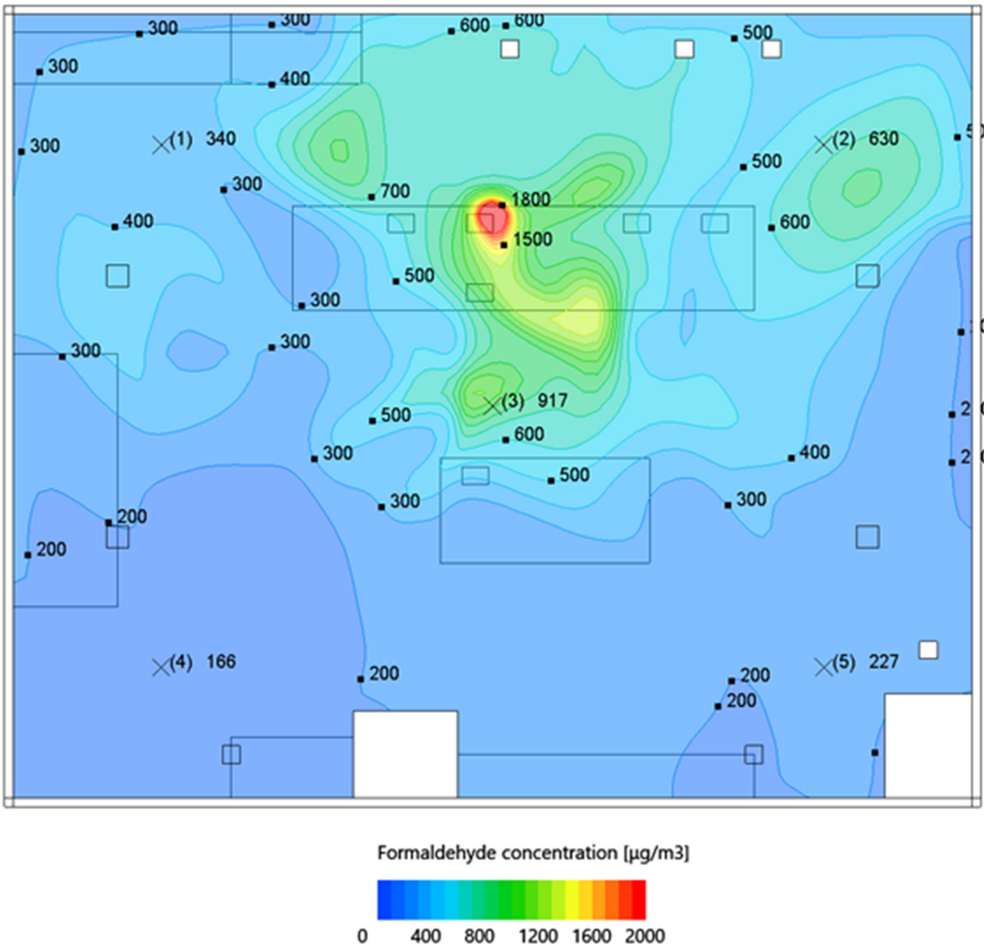

Figure 3 Contour plot of formaldehyde concentration at a cross-section with a height of 1.5 m (CFD)

Although the disparities observed between the CFD analysis and the actual measurements, we have identified that the CFD analysis, utilizing the estimated formaldehyde emission rate of 160 mg/h per work point, can be used to assess formaldehyde exposure risk in pathology laboratories. It is important to note that the formaldehyde emissions were estimated based on measurements conducted in a one pathology laboratory during this study. To further enhance the accuracy of these estimates, future research should aim to obtain measurements from multiple facilities, which would serve as a valuable guideline for ventilation design and risk assessment in pathology laboratories.

4. Conclusions

To effectively design ventilation equipment for pathology laboratories, it is imperative to determine the quantity of formaldehyde emission. We conducted measurements to ascertain the formaldehyde concentration in the pathology laboratory during actual operations and estimated the emission rate per work point. Furthermore, to validate the emission rate, we employed CFD analysis to simulate the concentration distribution of formaldehyde within the pathology laboratory and compared the results with the actual measurements. The analysis revealed that the amount of formaldehyde emitted per work point was approximately 160 mg/h, and the CFD analysis exhibited a wider dispersion of the concentration distribution compared to the actual measurements. The findings of this study, in conjunction with the CFD analysis, provide valuable insights for the design and risk assessment of ventilation equipment in pathology examination rooms.

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