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FIELD MEASUREMENTS OF AIR CHANGE EFFICIENCY IN LARGE REINFORCED PLASTICS PLANTS

Raimo Niemelä
Institute of Occupational Health, Department of Industrial Hygiene and Toxicology, Laajaniityntie 1, SF-01620 Vantaa, Finland

Arto Säämänen
Technical Research Centre of Finland, Safety Engineering Laboratory, P.O. Box 656, SF-33101 Tampere, Finland

Hannu Koskela
Turku Regional Institute of Occupational Health
Hämeenkatu 10 , SF-20500 Turku, Finland

SUMMARY

The air change efficiency and local mean age of air were determined in eight large lamination rooms where glassfiber-reinforced plastic products were manufactured. In these rooms the occurrence of airborne styrene monomer is a serious hygienic problem. The efficiency parameters were determined from the tracer gas decay tests by using nitrous oxide as a tracer gas. Concentrations of styrene were measured parallel with tracer gas tests. The values of air change efficiency and local air change index showed that the supply air was rather well-mixed with the room air in four plants whereas a tendency to displacement flow was observed in the others. The results show that distribution of fresh air differed notably from that of styrene. The measurements of concentration of styrene indicated high exposure levels.

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INTRODUCTION

Exposure to styrene monomer is a notable hygienic problem in the glassfiber-reinforced plastics industry. Exposure to styrene is heaviest during manual lamination with open molds, as the employees must work near large styrene emitting surfaces. During the past ten years the exposure limits for styrene have been lowered in the Scandinavian countries. The present 8-h TWA exposure limit in Finland and Sweden is 20 ppm. This low limit presupposes an increasing need for exposure control strategies in the GRP industry.

Isolation is a solution to the problem of occupational exposure to styrene in the automated and the closed mold production of reinforced plastic. However, an open mold does not permit complete enclosure. Ventilation therefore seems to be one of the most important engineering control measures. Typically, styrene vapors are emitted from strong, localized sources with varying evaporation rates. Because of the large variations in the size and production rates, as well as movable nature of work activities, general ventilation is frequently used for controlling airborne styrene. The creation of proper air flow patterns in large lamination spaces thus plays an important role in reducing concentration of styrene.

Simultaneous measurements of the air change efficiency and actual contaminant concentrations in industrial and other production buildings have proven to be a valuable tool in evaluating the performance of ventilation systems [1, 2, 3, 4].

The aim of this paper is to describe the function of the ventilation systems used in lamination rooms in terms of the air change efficiency, the local mean age of air, and the quotient between styrene concentration in the exhaust duct and in the occupied zone. Information on exposure levels, ventilation air flows and amounts of resin used are given in detail elsewhere [5].

MATERIALS AND METHODS

The field measurements of air change efficiency were carried out in eight large lamination halls, where big structures like boats were manufactured. The volume of the lamination rooms studied ranged from 3000 m^3 to 63000 m^3. Items were frequently laminated in large open areas without separation into different sections.

All plants used mechanical supply air and exhaust ventilation. The ventilation systems were roughly divided into three categories based on air distribution manners.

In three plants, the main supply air was introduced through grilles near the ceiling at one wall and distributed to the whole premises by means of horizontally and vertically angled high impulse jets. The air was exhausted at the opposite wall. (Configuration A)

Three plants relied on a downward ventilation configuration, where the supply air entered from diffusors or from a ductwork mounted at the ceiling. In two plants, air was extracted through the exhaust terminals near the floor, whereas in the third plant the air was evacuated through the local exhaust booths (Configuration B).

In the remaining two plants the fresh air was supplied through diffusors mounted on the wall and removed via the exhaust hoods at the side walls (Configuration C).

Air change efficiency, ϵ_a, is defined as [6]

$$\epsilon_a = \tau_n/2\langle\tau_i\rangle \qquad (1)$$

where τ_n is nominal time constant of ventilation system (obtained from the tracer decay in the exhaust). $\langle\tau_i\rangle$ is mean room age.

Local air change index, ϵ_i, is defined as

$$\epsilon_i = \tau_n/\tau_i \qquad (2)$$

where τ_i = local mean age of air at a measurement point.

Local ventilation index is usually defined as a relationship between the steady state concentration of the actual contaminant in the exhaust and at the selected points in the room [6]. In this paper the average concentration over the work day was used instead of the steady state:

$$\epsilon_i^c = C_e/C_i \qquad (3)$$

where C_e average styrene concentration in the exhaust. C_i average styrene concentration at sampling point in the occupied zone.

Air change efficiency , local mean age of air and nominal time constant were measured with the tracer decay technique [6]. Nitrous oxide , which was served as a tracer gas, was released at a constant flow rate into the supply air until the steady state was achieved. Release of tracer was stopped and concentration decay was monitored with an IR analyzer connected to a multipoint sampling network. The sampling sites were located 1.5 m above the floor in the zone of occupancy and in the exhaust duct. In five plants, tracer gas tests were repeated at the normal fan run or at the half fan run. The concentration of styrene was recorded at the same sampling sites with another IR analyzer during the entire work day.

RESULTS

Parameters describing supply air distribution in the laminant rooms are shown in table 1. Air change efficiency ($\tau_n/2<\tau>$) and local air change index (τ_n/τ_i) against local ventilation index (C_e/C_i) has been plotted in figures 1 and 2, respectively.

Table 1. Efficiency parameters of different ventilation systems in reinforced plastic plants

Ventilation configuration	Air change efficiency, % $\epsilon_a = \frac{\tau_n}{2<\bar{\tau}_i>}$		Local air change index in occupied zone $\epsilon_i = \frac{\tau_n}{\tau_i}$		Local ventilation index in occupied zone $\epsilon_i^c = \frac{C_e}{C_i}$	
	mean	range	mean	range	mean	range
Config A	60	57 - 64	1.12	1.01 - 1.35	1.06	0.44 - 2.00
Config B	53	49 - 60	1.00	0.66 - 1.14	1.93	0.78 - 5.00
Config C	51	51	0.96	0.83 - 1.10	1.17	0.76 - 1.64

Air change efficiency, ϵ_a, was highest (range 57-64) in ventilation configuration A. Also local air change indices were over 1.00 in all samples, meaning that supply air was distributed efficiently to the occupied zone in this ventilation design. In configurations B and C, air change efficiency was close to that of complete mixing (50 %). Mean values of the local air change indices were also close to 1.00, i.e. complete mixing, but there were places in the occupied zone where local air change index were lower than 1. This means that the supply air didn't reach the occupied zone very effectively.

The mean values of the local ventilation index in the occupied zone were highest in ventilation configuration B, whereas the lowest values were observed in ventilation configuration A (table 1). In all ventilation configurations, the mean values of local ventilation index were greater than 1, although there were large variations in the index.

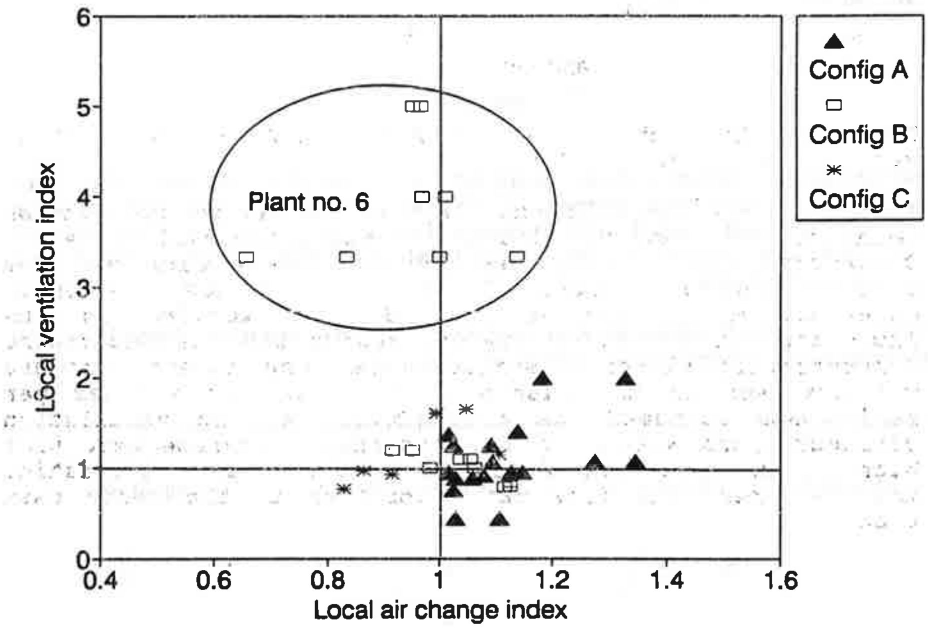

Fig. 1. Local air change index (τ_n/τ_i) vs. local ventilation index (C_e/C_i).

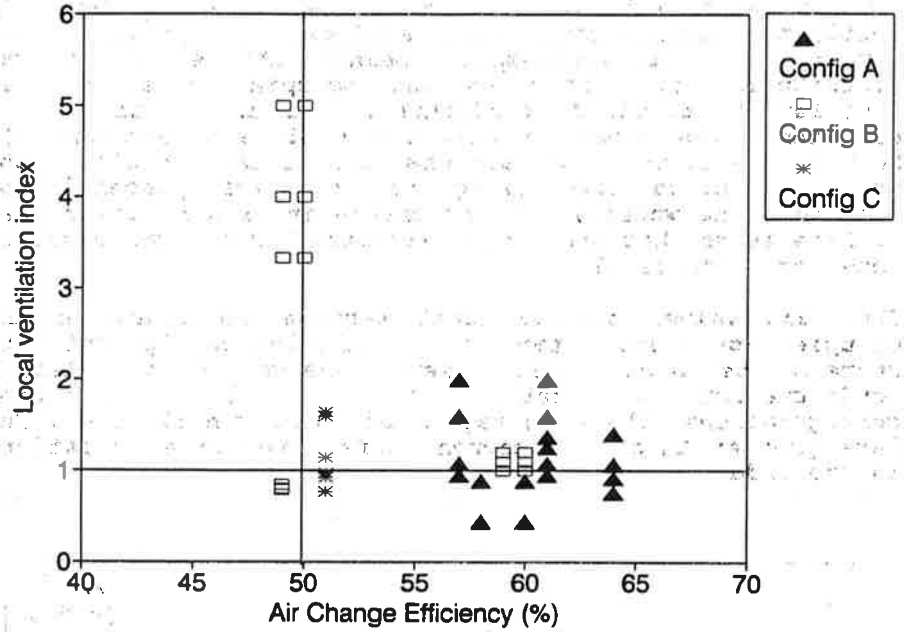

Fig. 2. Air change efficiency ($\tau_n/2<\tau>$) vs. local ventilation index (C_e/C_i).

Table 2 shows that the exposure to styrene in the Finnish reinforced plastics industry was generally heavy. Concentrations in the breathing zone were high and the current Finnish hygienic limit (20 ppm) was frequently exceeded. Major exposure was due to working in the immediate vicinity of a styrene source and the background concentration played a smaller role. The lowest exposure was observed in the plants where fresh air volumes per resin mass consumed was high (Config A). In ventilation configurations B and C concentrations of styrene were also high in the area samples in the occupied zone indicating too low fresh air flow rates compared to the resin mass used.

Table 2. Concentrations of styrene monomer and supply air flow rate compared to resin consumption in different ventilation configurations.

Ventilation configuration	Styrene concentration (ppm)				Air volume per resin consumption
	Occupied zone		Breathing zone		
	mean	range	mean	range	m^3-air/kg-resin
Config A	12	4 - 21	28	11 - 55	820
Config B	26	8 - 46	50	13 - 106	335
Config C	18	10 - 25	31	23 - 43	425

DISCUSSION

The values of air change efficiency in ventilation scheme A ranged from 57 to 64 %, which indicates a tendency to horizontal displacement flow. Two plants of ventilation configuration B yielded ventilation efficiency of 49 or 50 % indicating mixing flow patterns. In the third plant, a displacement flow tendency was observed, because air change efficiency amounted to 60 %. The values of air change efficiency obtained in the plants of ventilation category C with the supply terminals mounted on the side wall showed mixing flow patterns.

Air change efficiency is a parameter which describes average flow behaviour in the whole space between the supply and exhaust terminals. However, in large industrial settings, where air contaminants are emitted from different sources, local conditions in the zone of occupancy are of vital importance. Therefore, the values of the local air change index in the zone of occupancy may be more relevant than the parameters describing the average behaviour. The values of the local air change index in the plants of ventilation configuration A were always greater than one. This means that the supply air was distributed properly into the zone of occupancy. The local air change index ranged from 0.66 to 1.14 in configuration B and from 0.83 to 1.10 in configuration C. This variation showed a non-homogeneous distribution of the supply air in categories B and C.

From figures 1-2 we can see that the air change efficiency and the local air change index did not correlate with the local ventilation index. This means that air flow patterns differed from those of contaminants. In this case the difference was not unexpected, because there were strong, localized styrene sources which developed their own flow patterns.

The greatest values of the local ventilation index were attained with ventilation configuration B. However, the concentration of styrene at the breathing zone and in the general air in the occupied zone was the highest in configuration B.

Traditionally, the local ventilation index has been kept as a design parameter which should be greater than one. Then the contaminant removal is better than that of the reference case i.e. complete mixing. It is worth to note, however, that the value of the local ventilation index does not contain information on the occupants' exposure levels. In industrial premises, where toxic contaminants are present, this is a disadvantage, because the control of exposure to harmful contaminants is the most important task of ventilation system. In other words, a high value of a local ventilation index does'nt guarantee low absolute concentrations of contaminants. Therefore, a thorough diagnose of the ventilation system should include measurements of the absolute concentrations of highly toxic contaminants.

If the open molding methods are used in the GRP industry, it is unlikely that concentrations below the exposure limit of 20 ppm can be achieved by using general mixing ventilation only with the resin consumption rates common today. On the contrary, exposure levels below 50 ppm can be attained with properly designed general ventilation. However, the main reason for the high styrene exposure is strong, localized emission of styrene vapor and the worker's position close to the styrene source. In order to meet the present strict exposure limit, specialized ventilation techniques combined with the correct work practice should be used [7,8].

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