

Prediction of Toxic Substances Emission for Occupational Exposure Assessment

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Methods for predicting organic solvents, chromic acid, mineral oil, styrene, and sulphuric acid emissions in painting, metal degreasing, wood preservation, chromium electroplating, turning, grinding, making glass fortified polyester laminates and lead batteries charging, injection moulding of polystyrene plastics, and making polyurethane foam processes are described. Experimentally introduced equations are based on the essential parameters of these processes. Knowing the emission and the total flow rate of ventilation, it is possible to calculate toxic agent concentration, which is the basis of occupational exposure assessment.

emission occupational safety chemical hazards
methods for prediction of emission ventilation air purity

1. INTRODUCTION

The concentration of toxic substances in workplace air, which plays an important role in occupational safety, depends on two basic parameters:

- emission of toxic substance expressed in terms of mass unit per time unit (e.g., $\text{mg} \cdot \text{hr}^{-1}$),
- volume of air that dilutes the emitted substance; in practice it is the sum of flow rates of all kinds of ventilation systems, expressed in terms of volume unit per time unit (e.g., $\text{m}^3 \text{hr}^{-1}$).

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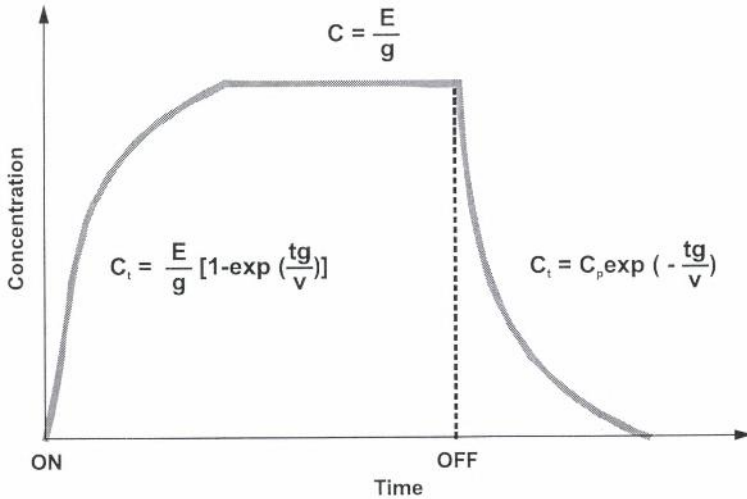


Figure 1. Concentration during the process. Notes. C —concentration, C_t —time dependent concentration, C_p —concentration at the switch off moment, V —volume of the hall, g —flow rate of ventilation system, E —emission, t —time.

Concentration of substances emitted into the air during a process—the factor that is the basis of occupational risk assessment, because the health hazard due to air impurities is estimated by comparing the measured concentration of toxic substances in workplace air and the threshold limit value (TLV) of this substance—reaches the steady-state constant value

$$C = E/q$$

where

C — concentration, mg/m^3 ,

q — sum of ventilation flow rates, m^3/min ,

E — emission, mg/min .

When designing a ventilation system, it is necessary to take into account both of these parameters to obtain air purity at the workplace. Until now, the emission of toxic substances has been unknown for most processes, and designers of ventilation systems have relied only on their own experience. Air purity at the workplace in factories built according to such designs may not be satisfactory, and the concentration of toxic substances may exceed threshold limit values, therefore, it may be

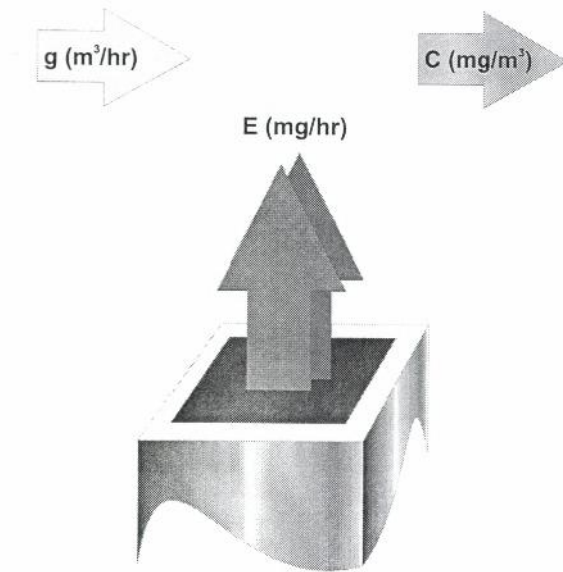


Figure 2. Dependence of concentration on flow rate of ventilation and emission.

Notes. g —flow rate of ventilation system, C —concentration, E —emission.

necessary to make corrections. Of course, such corrections are more substantial than creating a suitable ventilation system in the first place. Knowing the advantages of the possibility of determining emission, the European Committee for Standardisation (CEN) organised a working group WG15 "Emission of airborne hazardous substances from machines," which will examine problems of the emission of toxic substances from industrial machines. But the problem is much wider, because the machine is not always the source of pollution, for example, emission during brush painting.

The total emission of the factory is the sum of particular emissions of particular processes, and knowing the volume of this emission is helpful for making decisions about the purification of outlet gases emitted into the atmosphere. Purification—after degradation of the environment has already taken place—is very expensive due to the high cost of necessary additional equipment and to the possibly irreversible degradation of the environment. In order to solve this problem it is necessary to predict the amount of toxic substances emitted in a given technological process. It is not an easy problem because emission depends on many factors, such as the level of technology, kinds of machines, conditions of the process, and so on.

The problem is simple when there is only one dangerous compound in the air. The situation becomes much more complicated when there are a few compounds in the air at the same time. The summary level of exposure is expressed by the sum of quotients: concentration of each compound to its hygienic standard

$$\sum_i C_i / TLV_i$$

Conditions at the workplace are safe when the result of this expression is smaller than 1. Such a situation occurs in all processes in which organic solvents are emitted and in some cases summary concentration is not sufficient for risk assessment—in these cases it is necessary to know the percentage composition of the solvent. (Benczek, 1999).

Table 1 shows the composition of gases emitted during injection moulding of polystyrene ABS. Risk assessment for in this process requires some simplifications, because TLV values are not determined for all of these substances.

TABLE 1. Substances Emitted During Injection Moulding of Polystyrene ABS

Compound	Weight %	TLV
Butylcyclopropane	1.23	180 ¹
Relatives of hexane	0.79	500
Dimethylethylcyclohexane	1.25	500
Vinylcyclohexane	0.71	400
Butyltrimethylcyclohexane	0.33	500 ²
Ethylbenzene	4.98	100
Methylbenzene	2.86	100
Propylbenzene	1.66	100 ³
Aliphatic hydrocarbons C ₁₀ –C ₁₈	8.91	300 ⁴
Styrene	34.93	50
Alkilbenzenes	3.37	100 ³
1-Methyl-(1-methylethylidene)cyclohexane	15.26	500 ²
1,3,5.-trimethylcycloheptane	0.60	2000
Vinyl-2-metoxybenzene	0.47	50 ⁵
Buten-2-benzene	2.65	100 ³
Hexadecyl mercaptane	0.54	5 ⁶
Benzaldehyde	1.07	5
Unsaturated cyclohexanole	0.62	20 ⁷

Notes: 1—taken by analogy to propane, 2—taken by analogy to dimethylethylcyclohexane, 3—taken by analogy to ethylbenzene, 4—taken by analogy to petrol, 5—taken by analogy to styrene, 6—taken by analogy to dodecyl mercaptane, 7—taken by analogy to cyclohexane; TLV—threshold limit value.

2. CALCULATION OF EMISSION DURING TECHNOLOGICAL PROCESSES

In painting processes, the emission of organic solvents is determined according to the formula (Zawadzki, Mańkowska, & Kijeńska, 1980)

$$E = 1.5 a (35.29 + 0.84 t + 3.3 v)$$

where

a — parameter dependent on the type of paint,

t — surrounding temperature,

v — air velocity near by the painted surface.

Using this formula, it is possible to calculate emission of organic solvents during the first 30 min after painting.

The emission of mist of chromic acid during chromium electroplating can be calculated from the formula (Domański, 1987)

$$E = -0.087 + 0.099 k I(1 - h)0.015 t + 0.01 D$$

where

k — electrochemical equivalent of hydrogen,

I — current density,

h — current efficiency of chromium deposition,

t — temperature of the electrolyte,

D — cathodic current density.

The emission of mineral oil mist during metalworking with the use of oil-containing cooling agents for a turning process can be calculated from the formula (Benczek, 1989)

$$E = 7.77 \cdot 10^{-10} d n^2 \sqrt{\eta} + 4.7 t d V$$

where

d — diameter of a turned element,

n — number of turns of a spindle,

η — flow of cooling agent,

t — thickness of a chip,

V — cutting velocity.

and for a grinding process from the formula (Benczek, 1989)

$$E = 7.77 \cdot 10^{-10} d n^2 \sqrt{\eta} + 3 \frac{d^{0.25} n^{0.25} Z^{0.04}}{v^{0.05} B^{0.05} b^{0.05}}$$

where

- d — abrasive disk diameter,
- n — number of turns of abrasive disk,
- h — flow of cooling agent,
- Z — granularity of abrasive disk (scale 25–50),
- v — feed velocity of element,
- B — length of contact way,
- b — width of abrasive disk.

The emission of styrene during making glass fortified polyester laminates can be calculated from the formula (Kurpiewska & Kijeńska, 1991)

$$E = \{[75 \ln(n + 1) + 10 n] \exp(-T)\} + 2$$

where

- n — number of glass fibre mat layers,
- T — temperature.

This formula is valid for the determination of styrene emitted from 1 m² surface of laminate.

The emission of sulphuric acid mist during lead batteries charging can be calculated from the formula

$$E = 0.513 n I$$

where

- n — number of cells,
- I — average charging current.

This formula is valid in the steady-state (when cells are fully charged) and for temperature 25 °C. For other temperatures corrections should be introduced.

The total emission during processing of polystyrenes can be calculated from the formula (Benczek & Kurpiewska, 1996)

$$E = 5 \cdot 10^{-4} \sqrt{mp}$$

where

m — mass of polystyrene processed per hour,

p — total surface of products making by,

$5 \cdot 10^{-4}$ — coefficient.

Emission of all substances emitted during processing of polyurethane foam can be calculated from the formula

$$E = 0.004 m$$

where

m — mass of components processed per hour,

0.004 — coefficient

The emission of organic solvents can be calculated from the formulas (Benczek, Gawęda, & Madej, 1997)

• trichloroethylene	$E = (657 v + 63.6 t + 699.6) \cdot P_r + 34.7 P$
• naphtha solvent	$E = (109 v + 9.3 t + 4.9) \cdot P_r + 26 P$
• naphtha anticor	$E = (9.1 v + 0.55 t + 5.65) \cdot P_r + 34.5 P$
• 1-butanol	$E = (72 v + 6.3 t + 17) \cdot P_r + 31.3 P$
• 1,1,1-trichloroethane	$E = (1403 v + 94.7 t + 805.6) \cdot P_r + 38.5 P$
• extraction naphtha	$E = (632 v + 49.5 t + 1147) \cdot P_r + 19 P$
• petroleum (mineral) spirits	$E = (160 v + 12 t + 76.7) \cdot P_r + 19.2 P$
• wood preservatives	$E = (516 v + 2 t + 42) \cdot P_r$
sum of solvents)	

where

v — air velocity near surface of solvent, which in quiet air equals 0.3;

t — temperature;

P_r — surface of solvent;

P — surface of elements degreased in 1 hr.

This formula makes it possible to estimate organic solvent emission in all technological processes in which there is evaporation of solvents, for example, painting, wood preservation, impregnating of porous material, gluing, cleaning, filing of open tanks, handling of solvents, and many, many others.

Due to the possibility of using a relatively simply and universal approach, these formulas are the most suitable for determining organic solvent emission during metal degreasing processes.

3. FINAL REMARKS

All presented and examined formulas should be useful for each corresponding technological process independently of the practical way and of the machines (different manufacturers, old or new, big or small, simple or complicated). That is why the final solving of the problem cannot be precise. It is acceptable when a formula describing the emission from a typical process is about 50% accurate. We have to remember that these equations have to be modified if technologies change (Benczek, 1997).

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