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COMPARISON OF AIR POLLUTION IN THE WORKING ENVIRONMENT DURING *IN SITE* TREATMENT OF INFECTIOUS MEDICAL WASTE BY CONVERTOR AND AUTOCLAVE STERILIZATION

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ABSTRACT

The aim of the present study is the comparison of ambient pollution in working environment during infectious medical waste treatment in two relevant health care institutions in the Republic of Serbia – The Blood Transfusion Institute of Serbia and The Clinical Centre of Serbia by different sterilization methods (sterilizer–convertor and autoclave, respectively). Monitoring and analysis of the following chemical compounds were performed in both institutions: water vapor, carbon dioxide, carbon monoxide, hydrochloric acid, methane, ethane, propane, hexane, formaldehyde, benzene, toluene, m-xylene, phenol, acrolein, ethanol, ethyl acetate, ethylamine, ethylene oxide, methanol, dimethyl disulphide, dimethyl sulphide, ethyl mercaptan, methyl mercaptan, freon 11 (trichlorofluoromethane), carbonyl sulphide and hydrogen chloride. The determination of vapor-phase concentrations was done by extractive *Fourier* transform infrared spectroscopy. Monitoring of ambient pollution during infectious medical waste sterilization has shown that mercaptans, acrolein, formaldehyde, dimethyl sulphide, and ethylene oxide are emitted in both health institutions, in concentrations which are not permitted by regulations, while increased concentrations of hydrogen chloride and phenol were found in the Clinical Centre of Serbia. A comparison of ambient pollution with two different sterilization methods has shown that higher concentrations of pollutants are emitted at higher temperatures. Considering the fact that mentioned compounds exhibit high toxicity, hence represent the risk to air quality in working and living environment, i.e. represents a risk to human health it is necessary to revise and improve the existing treatment methods.

KEYWORDS:
Waste, infectious, *in site*, sterilization, working environment, ambient pollution, VOCs

INTRODUCTION

Medical waste includes each and every waste produced during activities as health protection, immunization, diagnostics, medical treatment of people and animals, scientific research and laboratory testing [1]. Medical waste treatment can be *in site* or *off site*. *In site* procedures include: autoclaving, chemical treatment and microwave treatment. *Off site* medical waste treatment includes: incineration, disposal of waste material by burial (landfilling) and plasma pyrolysis [2].

In the Republic of Serbia, medical, infectious and highly infectious waste is defined as hazardous waste which, due to its pathogenicity and number of microorganisms, represents a risk to human health [3]. Space where waste disinfection /sterilization is done must comply with requirements established by a special regulation, provided that emission of pollutants in the air does not exceed prescribed limit values. The efficiency of infections medical waste treatment is tested during each treatment by physical and chemical indicators, while microbiological control of efficiency is done once a month [3].

During infectious medical waste treatment at high temperatures, combustion products are formed, as well as products of unstable compound dissolution, which can, without standard and adequate equipment, penetrate the working environment. Chemical pollutants that can be emitted into the working environment during infectious medical waste treatment present some harmful gases and vapors belonging to the group of volatile organic compounds (VOCs). These compounds represent highly reactive or toxic gases due to high volatility

under normal atmospheric conditions [4]. VOCs are mainly characterized as organic compounds possessing relatively high vapor pressure, while in EU, these group is defined as organic compounds possessing the boiling point less than 250°C at atmospheric pressure [5].

By the provisions of the National Institute for Occupational Safety and Health, USA (NIOSH), defined are recommended exposure levels (RELs) [6]. NIOSH RELs level (concentration) of chemical pollutants defines the total weighted average (TWA) representing an average concentration of pollutants over a time interval of up to 10 working hours during one working week (40 h). The purpose of this research is the comparison of ambient pollution in the working environment during infectious medical waste treatment in two medical institutions – Blood Transfusion Institute of Serbia and Clinical Centre of Serbia, by employing different sterilization methods in order to assess the risk to the health of employees.

MATERIALS AND METHODS

Material and preparation for treatment. All treated samples are classified as infectious medical waste and they are collected and analyzed according to methods of *The Occupational Safety and Health Administration*, USA (OSHA) and NIOSH, for each, particular emitted pollutant and with additional version of test method number 320 by the side of the Environmental Protection Agency (EPA -Test Method 320) [6-8], as well as by the two regulations of the Republic of Serbia, The Regulation on Measurement of Air Pollutant Emission from Stationary Pollution Sources [9] and Regulation on Monitoring Conditions and Air Quality Requirements [10], according to Standard reference methods SRPS EN and SRPS EN ISO.

Prior to treatment, medical infectious waste is disposed into PE bags/containers. Such waste consists of the following: sharp objects (lancets, needles, object glasses and similar), syringes, tubes and ampoules from used medicines (unless the medicines are cytotoxic), unrecognizable tissue from diagnostic and non-surgical procedures, waste created in hemodialysis and peritoneal dialysis, bandage material and pads stained by blood and other bodily secretions and excretions, blood/blood components in PVC bag, used plastic hoses, test tubes, Petri dishes, sanitary towels, dippers stained by bodily liquids/excretions, waste from clinical and/or test laboratories and similar, infectious waste categories.

Infectious medical waste treatment. Treatment by sterilizer – convertor. Properly packed, infectious medical waste was treated by sterilizer-convertor of the following model: Sterilizer-convertor (Newster Group, Italy) in the Blood Transfusion Institute of Serbia. Sterilizer – convertor performs sterilization and fragmentation of infectious and potentially infectious waste, as well as sharp objects, for the purpose of simultaneous sterilization, physical modification, dehydration and reduction in volume and mass. The sterilization procedure is done thermally and chemically, at the temperature of 155°C in a humid environment, with the addition of sodium hypochlorite, for 30 minutes. After the end of this process, treated waste is sterile, dry, crushed and unrecognizable, and it can be used as the source of energy, and, based on these new characteristics, it is classified into a municipal waste category.

Waste Treatment by Autoclave. Adequately packed medical waste is treated in Getinge HS 66 sterilizer (Getinge Group, Sweden) at the Clinical Centre of Serbia. This device represents a standard sterilizer, an autoclave operating under high pressure, possessing a vertically sliding, automatic door with the opening of 660 x 660 mm. The dominant sterilization medium is water vapor at the temperature of 121-134°C.

Ambient Pollution Monitoring and Pollutant Concentration Measurement. All concentrations have been measured according to the Regulation on Measurements of Air Pollutant Emission from Stationary Pollution Sources ("Official Gazette of RS", No. 5/2016, Articles: 3-6, 11-16, 21, 29, 30, 40, 41) [9].

Determination of concentrations from the vapor–phase was done by extractive infrared spectroscopy with *Fourier* transform (FT-IR) on Analyzer Gasmet DKS-4000 device, Finland, according to prescribed operating requirements of analyzers [9].

In both medical institutions 108 measurements through 3 cycles were performed (36 per cycle, first measurement 2 minutes after start; 1-36, 37-72, 73-108). Determination of pollutants is done by application of a probe (the probe relating to Analyzer Gasmet DKS-4000 device, Finland) that moves in 4 to 5 spots in the level of respiratory organs and the average concentration value is taken into account. In the case of both institutions, the area of working premises where sterilization was performed was less than 30 m^2, and along with wall height, it makes the volume allowing the use of one suction spot [9].

During medical infectious waste treatment in both institutions, monitoring and analysis of the following chemical compounds were done: water vapor, carbon dioxide, carbon monoxide, hydrochloric acid, methane, ethane, propane, hexane, formaldehyde, benzene, toluene, m-xylene, phenol, acrolein, ethanol, ethyl acetate, ethylamine, ethylene oxide, methanol, dimethyl disulfide (DMS),

dimethyl sulfide, ethyl mercaptan, methyl mercaptan, Freon 11 (trichlorofluoromethane), carbonyl sulfide and hydrogen cyanide [6, 9-10].

RESULTS AND DISCUSSION

In site measurement of pollutant emission in two measuring points in the relevant health care facilities in the Republic of Serbia was done by the side of an accredited laboratory (SRPS ISO/IEC 17025:2006) for physical and chemical air testing, pursuant to the above mentioned Regulation on Measurement of Air Pollutant Emission from Stationary Pollution Sources [9] and the Regulation on Monitoring Conditions and Air Quality Requirements [10]. All samples have been collected and analyzed according to NIOSH or OSHA methods, which are specific for the given compound [6]. The experimental part of testing has been based on pollutant concentration measurement in ambient air concerning two health institutions treating infectious medical waste.

Qualitative and quantitative analysis of emitted compounds during medical waste treatment. Measured concentrations of emitted compounds were shown as average values per each cycle with comparative TWA values for each institution (Tables 1 and 2). Some of the toxic VOCs, during the process of infectious medical waste sterilization, have shown concentrations that were above permitted TWA concentrations, in both institutions. Such compounds present a risk to staff in the immediate working environment, particularly after multiple exposures. In Blood Transfusion Institute of Serbia, during three sterilization cycles, increased are concentrations of the following: mercaptan (methyl and ethyl mercaptan), acrolein, formaldehyde, DMS and ethylene oxide. In addition, during sterilization treatment in the Clinical Centre of Serbia, the following concentrations have been increased: hydrogen chloride, formaldehyde, phenol, acrolein, and DMS, as well as methyl and ethyl mercaptan.

Mercaptans, or thiols according to IUPAC nomenclature, are similar to alcohols by their chemical structure, whereas instead of C–O bond they possess C–S bond, so-called C–SH thiol group. This compound group has a strong and repulsive odor, while lower mercaptans show high toxicity, similar to hydrogen sulfide. Their toxicity is indicated by affecting a central nervous system in a similar manner as alcohols, but with much higher toxicity [11-12]. This can be concluded based on maximally permitted ambient concentrations (TWA) which are, for the example for ethanol, set to the value of up to 1900 mg/m^3, while they are set to 1.3 mg/m^3 concerning ethyl mercaptan, and/or to the value of 1.0 mg/m^3 regarding methyl mercaptan [6].

TABLE 1
Concentrations of emitted pollutants by cycles in Blood transfusion Institute of Serbia

Emitted substances	I cycle (mg/m^3)	II cycle (mg/m^3)	III cycle (mg/m^3)	TWA (mg/m^3)
Water vapor, H_2O	2.69	1.64	1.60	/
Carbon dioxide, CO_2	0.26	0.25	0.29	54000
Carbon monoxide, CO	4.58	2.84	2.69	229
Hydrogen chloride, HCl	6.95	3.39	3.48	7
Methane, CH_4	0.03	0.70	3.47	1800
Ethane, C_2H_6	0.00	0.00	0.03	1800
n-Propane, C_3H_8	0.14	0.00	0.18	1800
Hexane, C_6H_{14}	33.57	24.40	18.70	72
Formaldehyde, CHOH*	***0.58***	***0.78***	***0.72***	***0.369***
Benzene, C_6H_6	1.99	1.30	1.46	3.25
Toluene, C_7H_8	0.33	0.72	0.31	192
m-Xylene, C_8H_{10}	1.76	1.66	5.72	221
Phenol, C_6H_6O	1.84	0.05	0.25	8
Acrolein, C_3H_4O	***5.31***	***5.31***	***3.79***	***0.25***
Ethanol, C_2H_6O	0.00	0.00	0.00	1900
Ethyl acetate, $C_4H_8O_2$	0.15	0.15	0.00	1400
Ethylamine, C_2H_7N	0.00	0.00	1.05	18
Ethylene oxide, C_2H_4O	***0.00***	***0.00***	***0.72***	***0.18***
Methanol, CH_4O	0.00	0.00	0.00	260
Dimethyl disulfide, $C_2H_6S_2$	***8.73***	***8.73***	***4.07***	***1.9***
Dimethyl sulfide, C_2H_6S	0.09	0.04	0.09	5
Ethyl mercaptan, C_2H_6S	***23.24***	***16.55***	***3.48***	***1.3***
Methyl mercaptan, CH_4S	***14.91***	***2.72***	***6.63***	***1***
Freon 11, CCl_3F	4.90	3.91	4.10	5600
Carbonyl sulfide, COS	0.14	0.03	0.03	12.28
Hydrogen cyanide, HCN	3.73	1.80	1.78	5

*Pollutants which exceeded limit emission concentrations according to TWA values

TABLE 2
Concentrations of emitted pollutants by cycles in Clinical Centre of Serbia

Emitted substances	I cycle (mg/m^3)	II cycle (mg/m^3)	III cycle (mg/m^3)	TWA (mg/m^3)
Water vapor, H_2O	2.38	2.19	2.06	/
Carbon dioxide, CO_2	0.22	0.21	0.26	54000
Carbon monoxide, CO	62.96	2.08	0.11	229
Hydrogen chloride, HCl*	***8.50***	***2.25***	***2.13***	***7***
Methane, CH_4	5.96	6.83	6.30	1800
Ethane, C_2H_6	1.84	0.48	0.64	1800
n-Propane, C_3H_8	3.21	0.50	0.71	1800
Hexane, C_6H_{14}	14.97	2.76	2.79	72
Formaldehyde, CHOH	***0.07***	***0.86***	***0.94***	***0.369***
Benzene, C_6H_6	2.65	1.50	1.88	3.25
Toluene, C_7H_8	7.32	2.01	1.21	192
m-Xylene, C_8H_{10}	4.13	0.08	0.02	221
Phenol, C_6H_6O	***5.93***	***4.39***	***8.91***	***8***
Acrolein, C_3H_4O	***8.11***	***5.14***	***3.84***	***0.25***
Ethanol, C_2H_6O	1.08	0.31	0.67	1900
Ethyl acetate, $C_4H_8O_2$	11.97	0.71	0.44	1400
Ethylamine, C_2H_7N	0.00	0.21	0.36	18
Ethylene oxide, C_2H_4O	***9.56***	***0.03***	***0.02***	***0.18***
Methanol, CH_4O	0.00	0.00	0.04	260
Dimethyl disulfide, $C_2H_6S_2$	***2.16***	***1.44***	***1.82***	***1.9***
Dimethyl sulfide, C_2H_6S	1.55	0.00	0.09	5
Ethyl mercaptan, C_2H_6S	***6.36***	***3.77***	***3.48***	***1.3***
Methyl mercaptan, CH_4S	***2.91***	***6.93***	***6.63***	***1***
Freon 11, CCl_3F	0.88	3.55	4.10	5600
Carbonyl sulfide, COS	0.06	0.02	0.03	12.28
Hydrogen cyanide, HCN	2.79	1.77	1.78	5

*Pollutants which exceeded limit emission concentrations according to TWA values

Acrolein shows extremely high toxicity, associating it with brain damage, multiple sclerosis, Alzheimer disease, cardiovascular diseases, and diabetes, as well as neuro-, hepato- and nephrotoxicity [13]. Formaldehyde exhibits neurotoxic effect to the morphology of neurons and biochemical parameters [14], while DMS toxicity manifests by mucosal inflammation of eyes, nose, oropharynx, and airways, tissue edema and necrosis, hepatic and cardiac insufficiency, as well as by convulsions, delirium and coma [15]. Chronical exposure to ethylene oxide causes irritation of eyes, skin, nose, throat, and lungs, as well as damage to the brain and nervous system. It is considered a carcinogenic substance, namely by inhalation [16].

Hydrogen chloride and phenol, whose average concentrations are slightly increased in reference with permitted concentration values during sterilization in the Clinical Centre of Serbia, possess high toxicity as well. Inhalation of hydrogen chloride may cause nasal cavity irritation and upper respiratory tract irritation, ulcerations, coughing, oppression of the lungs and shortness of breath. Higher concentrations can cause tachypnea (accelerated shallow breathing), lung edema and suffocation [17]. Notwithstanding high carcinogenic properties of phenol and phenol derivatives, due to their low volatility, toxicity hazard caused by inhalation is limited. Also, due to larger molecular mass, and/or density, phenol vapors are distributed faster towards lower layers of ambient air in working space, thus reducing the possibility of exposure to toxic effects by inhalation [18].

Comparison of pollutant emission during treatment in convertor and autoclave. Figure 1 shows a comparison of average increased emitted pollutant concentrations during treatment of medical infectious waste in the Blood transfusion Institute of Serbia and Clinical Centre of Serbia. Based on the results it is concluded that, at higher temperatures during sterilization in the Blood Transfusion Institute, extremely toxic compounds are emitted, the concentration of which greatly exceeds set, permitted limit concentrations. Namely, at 155°C in a humid environment, mercaptan emission occurs in the concentrations which are even about twenty times higher than permitted ones. While, when applying a method of sterilization by classical water vapor autoclaving at the temperature range from 121 to 134°C, mercaptan concentration is about six times higher. Application of higher temperatures causes a release of higher, toxic VOCs, therefore it is necessary to consider the method of working environment protection, primarily for the sake of directly exposed medical staff.

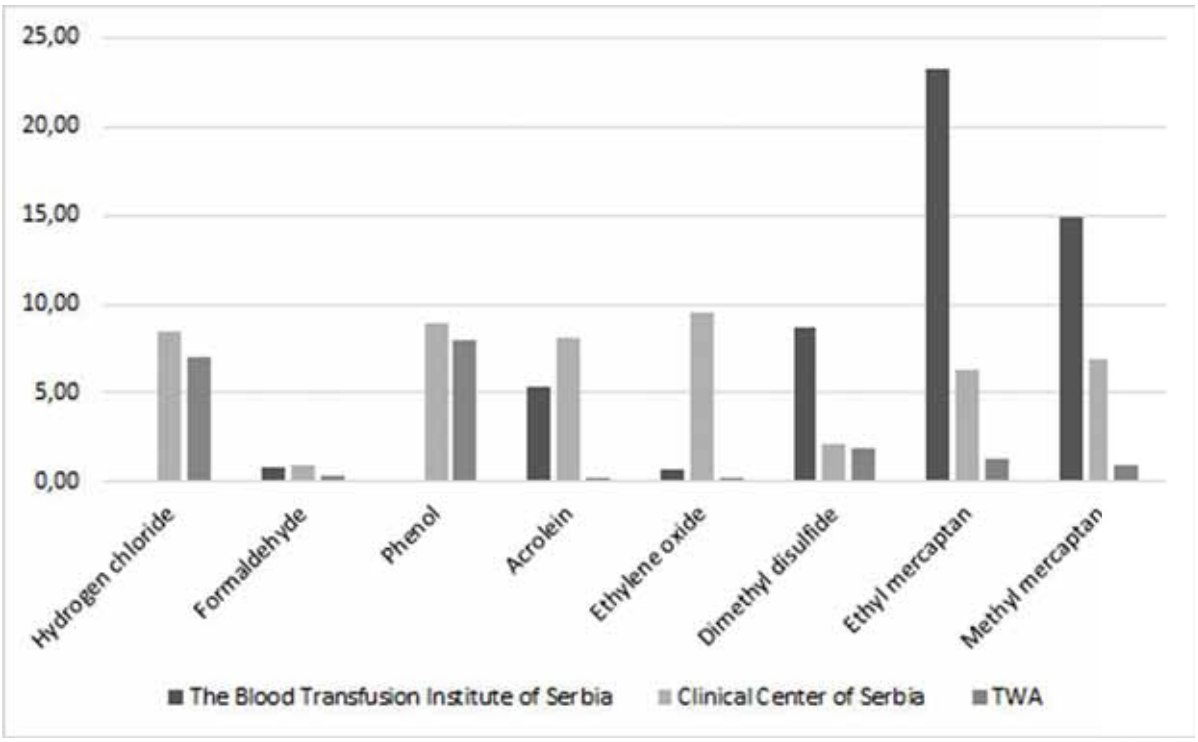

FIGURE 1
The highest measured increased VOC concentrations during sterilization of medical infectious waste in observed health institutions (mg/m^3)

CONCLUSION

Monitoring of ambient pollution during infectious medical waste sterilization has shown that mercaptans, acrolein, formaldehyde, DMS and ethylene oxide are emitted in concentrations that are not permitted by regulations in both health institutions, whereas concentrations of hydrogen chloride and phenol are increased in the Clinical Centre of Serbia. Comparison of two, different sterilization methods concerning ambient pollution has shown that higher pollutant concentrations are emitted at higher temperatures. In view of the fact that stated compounds exhibit high toxicity, hence represent the risk to air quality in working and living environment, it is necessary to revise and improve the existing treatment methods. In addition, the consequence of these pollutants' emission into the working environment can lead to their spreading into the living environment, therefore, air quality monitoring within the working environment is necessary.

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