Comparison between measured and modelled data on occupational exposure to organic solvents in degreasing, varnishing and painting activities performed in a Romanian company

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Abstract. This study aims to highlight the similarities and differences between occupational exposure measured (personal and static) and modelled data using the Tier 2 Advanced REACH Tool (ART 1.5) for some organic solvents used in degreasing, varnishing and painting activities. The measurements were performed between 2020 and 2022 in a Romanian company manufacturing metallic components for the energy industry. The conclusion of the study will allow identifying some of the uncertainties related to the use of modelled data versus measured data, and to decide on the adequate operational conditions (OCs) and risk management measures (RMMs) to implement in place, in accordance with the hierarchy of control principles.

1 Introduction

Exposure to solvents and other organic liquids is one of the most common chemical health risks at workplaces. Vapors of solvents can accumulate in confined places and stay there for a long time, presenting risks for health and property [1].

Solvents enter the body by inhalation, by swallowing and through the skin. The effect depends on several factors, their vapors and mists have various effects on human health. Many of them have a narcotic effect, causing fatigue, dizziness and intoxication [1]. High doses may lead to unconsciousness and death. Exposure to large doses of solvents may slow down reaction-time and affect rational judgment, that may increase the risk of accidents both at work and outside, such as in the traffic on the way back home.

Solvents irritate the eyes and the respiratory tract. Some solvents penetrate the skin and enter the blood circulation. Solvents may damage the liver, kidneys, heart, blood vessels, bone marrow and the nervous system [1].

In Romania, the workers’ exposure to organic solvents (like hexane) is also often seen at the workplaces from leather goods and the footwear industry, in the lakes, inks and paints, polymerization solvent for the production of polypropylene and high polyethylene density,
as well as in the process of obtaining refined vegetable oils. Long exposure to organic solvents causes changes neurobehavioral of individuals, with impact on their quality of life. Acute symptoms are moderate anesthesia; at high concentrations it produces euphoria, drowsiness, headache, nausea. Chronic symptoms are parenthesis, asthenia, limb fatigue, unsteady gait, difficult, muscle atrophy, but also damage to the optic nerve with narrowing of the visual field [2].

Controlling exposures to hazards in the workplace is vital to protecting workers. The hierarchy of controls principles is a way of determining which actions will best control exposures [3]. The hierarchy of controls has five levels of actions to reduce or remove hazards. The preferred order of action based on general effectiveness is:

1. Elimination
2. Substitution
3. Engineering controls
4. Administrative controls
5. Personal protective equipment (PPE) [3].

Following the hierarchy of control principles can support the companies in implementing appropriate operational conditions (OCs) and risk management measures (RMMs) to minimize the workers’ exposures to organic solvents, for example, by using substitution, automation, closed systems, mechanical ventilation, etc.

![Hierarchy of controls principles](image)

**Fig. 1.** Hierarchy of controls principles

This study aims to present and highlight the similarities and differences between measured (personal and static) data and modelled data for some organic solvents usually used in activities such as degreasing, varnishing and painting. Its purpose is also to identify the uncertainties related to the use of modelled data versus measured data in evaluating the workers’ inhalation exposure to organic solvents and implementing appropriate protective measures. It is well known that occupational risk management activities specific to the work equipment used in metal processing industry can ensure the necessary conditions for the safe and compliant use of working equipment, and also to increase the competitiveness of the companies on the market economy [4].
2 Material and methods

The measurements presented in this paper were performed by the institute’s experts during three monitoring campaigns (between 2020 and 2022), in a Romanian company specialized in the manufacture of metallic components for the energy sector.

In case of the modelled data, the Advanced REACH Tool (ART) version 1.5 was used, as it is considered the most accurate model for organic solvents and pesticides, with a significant correlation (P < 0.05) among modelled and measured data [5]. High tier models (Tier 2), such as ART, use a great number of more detailed input parameters to produce estimates of higher accuracy and confidence, but still for a wide range of applications [6].

2.1 Measured data (static and personal)

The measurements presented in this paper were undertaken using Ion Science Tiger XTL VOC detector. This detector has a resolution of 0.1 ppm, a maximum reading of 5,000 ppm and a response time below 2 seconds, using a 10.6 eV lamp. Photoionization detection (PID) sensor technology with humidity resistance is used. The equipment can detect and measure more than 100 volatile compounds, including organic solvents.

Due to the relatively high limit of quantification (LOQ of 0.1 ppm) and uncertainty of the PID sensors (solvents concentration is estimated using response factors), the measured value using PID detectors are mainly used to evaluate the potential significant releases, to check the compliance with the permit procedures, and also the equipment tightness. The uncertainty of the PID measurements at low concentration in the workplace atmosphere can be considered acceptable for this purpose.

The measurements were performed during specific activities such as degreasing, varnishing and painting, considering the duration of each activity. According to EN 689, measurements shall be performed on sufficient days and during various specific operations in order to gain insight the pattern of exposure [7]. It is recommended, mainly for testing compliance with 8 h OELs (which is not the case in this study), that if the duration of the workers’ exposure is less than 2 hours, the sampling duration should cover the whole period of exposure [7].

Personal measurements were performed in the breathing area of the workers, corresponds to a hemisphere (generally accepted to be 30 cm in radius) extending in front of the human face, according to EN 1540 [8]. Static measurements were performed in fixed location in the proximity of the emission sources, for the tasks carried on by using organic solvents.

In case of mixtures, the concentration was estimated based on the response factors, the percentage of the substance in the mixture, and the volatility of the substance.

Measured data were expressed as 8 h TWA (time weighted average) concentration. The results of the measurements are presented in Table 1 in chapter 3.1.

2.2 Modelled data using ART 1.5

The Advanced REACH Tool, ART (version 1.5) uses a mechanistic model to estimate the exposure. This tool provides estimates of the whole distribution of exposure variability and uncertainty, allowing the user to produce a variety of reasonably foreseeable realistic and worst-case exposure estimates [9]. The model differentiates between different exposure processes: vapor, mist, and dust. This means that fumes, fibers, and gases are not considered by the model [10]. Chemical agents in workplace atmosphere are often present in both gaseous and non-gaseous phases at the same time, therefore, validated methods that can measure the combined concentration in both phases are required [11].
ART model calculates an overall distribution for full-shift exposure based on the input parameters introduced by the user. For a reliable mass-balance-based exposure-modelling approaches, measured values for model input parameters (in particular, emission rates) are required. In the absence of measurements, input parameters can be estimated, but with the acknowledgement that this introduces uncertainty into the model output [12].

According to the ART User Guide, the model involves several steps with general questions on the scenario (scenario overview) and the configuration of the relevant activities [12]. The model starts with a general description of the scenario, the chemical name of the substance of interest, CAS No., and an overview of the activities (up to four activities), with their specific duration. The total duration that should be around 480 minutes (normal shift duration). If applicable, a non-exposed period can also be mentioned.

For each activity identified, input parameters should be selected. An example of the input parameters in case of activities using organic solvents is presented in Table 1.

Table 1. Input parameters selection in ART 1.5 model for organic solvents

<table>
<thead>
<tr>
<th>Input parameters</th>
<th>Selection on this particular case (organic solvents)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product type</td>
<td>Liquids</td>
</tr>
<tr>
<td>Substance emission</td>
<td>Volatility</td>
</tr>
<tr>
<td>Activity Class (AC)</td>
<td>Depends on the product type (e.g., spray applications; spreading of liquid products, handling of contaminated objects, etc.). Each AC has a unique set of questions.</td>
</tr>
<tr>
<td>Localized controls</td>
<td>E.g. suppression techniques, containment, type of local exhaust ventilation</td>
</tr>
<tr>
<td>Surface contamination</td>
<td>Level of general housekeeping indicates the contribution to exposure from re-suspension of deposited contaminants on surrounding surfaces</td>
</tr>
<tr>
<td>Dispersion</td>
<td>For indoor environments the level of dispersion is based on the room size and number of air changes per hour</td>
</tr>
<tr>
<td>Segregation</td>
<td>Types of isolation of the source from the work environment (i.e. process fully enclosed (air tight))</td>
</tr>
<tr>
<td>Separation</td>
<td>Types of personal enclosure</td>
</tr>
<tr>
<td>Near field/Far field sources</td>
<td>In the breathing zone of the worker/secondary sources present</td>
</tr>
</tbody>
</table>

After all the activities of the exposure scenario have been configured, the model will run. The results are displayed in a separate output page [13].
Generally, the 90th percentile value (the value that provides the exposure level which has a 10% probability of being exceeded by the exposure from a randomly selected worker on a randomly selected day) it is used to estimate the workers’ exposure [13].

ART does not take into account the effectiveness of the respiratory protective equipment (RPE) [9]. The effectiveness of the RPE should be introduced separately, to obtain the estimate of actual inhalation exposure.

3 Results and Discussion

3.1 Results

The results of the measurements (static and personal) performed during the monitoring campaigns between 2020 and 2022 for the specific activities mentioned are presented in Tables 2 and 3. Most of the measurements were performed in the Mechanical assembly workshop, but also in the Storage room, in the proximity of the emission sources.
In order to allow an easy comparison with the measured data, the modelled data estimated using ART 1.5 are also presented in Tables 2 and 3. The results are presented as 90th percentile full-shift exposure, considering the duration of the specific tasks (provided by the company) and also the non-exposure duration. A combined exposure was not considered, as the operators perform specific tasks during the shift.

As the operational conditions were similar during 2020-2022, one set of modelled data is provided within the scope of this study. The input parameters were selected according to the specific situation at the workplace (e.g., good natural ventilation, local exhaust ventilation: extraction hood, volume of the workshop, segregation, etc.)

**Table 2. Summary of the measured and modelled data for ethyl acetate and acetone**

<table>
<thead>
<tr>
<th>Date</th>
<th>Activity</th>
<th>Duration of the activity</th>
<th>Route of exposure</th>
<th>Method of assessment</th>
<th>Exposure value (8h TWA) (mg/m³)</th>
<th>OEL* (8h) (mg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10/2020</td>
<td>Preparation</td>
<td>10 min./shift</td>
<td>Inhalation</td>
<td>Measured (static)</td>
<td>5.3</td>
<td>734</td>
</tr>
<tr>
<td>05/2021</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.7</td>
<td></td>
</tr>
<tr>
<td>09/2022</td>
<td></td>
<td></td>
<td></td>
<td>Modelling 90th perc.</td>
<td>9.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>10/2020</td>
<td>Degreasing</td>
<td>300 min./shift</td>
<td>Inhalation</td>
<td>Measured (personal)</td>
<td>280.3</td>
<td>734</td>
</tr>
<tr>
<td>05/2021</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>421.2</td>
<td></td>
</tr>
<tr>
<td>09/2022</td>
<td></td>
<td></td>
<td></td>
<td>Modelling 90th perc.</td>
<td>337.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>960</td>
<td></td>
</tr>
</tbody>
</table>

* Informative, according to Government Decision no 1218/2006 [14]

**Table 3. Summary of the measured and modelled data for n-Butanol, xylene and ethylbenzene**

<table>
<thead>
<tr>
<th>Date</th>
<th>Activity</th>
<th>Duration of the activity</th>
<th>Route of exposure</th>
<th>Method of assessment</th>
<th>Exposure value (8h TWA) (mg/m³)</th>
<th>OEL* (8h) (mg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10/2020</td>
<td>Preparation</td>
<td>10 min./shift</td>
<td>Inhalation</td>
<td>Measured (personal)</td>
<td>0.7</td>
<td>100</td>
</tr>
<tr>
<td>05/2021</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.2</td>
<td></td>
</tr>
<tr>
<td>09/2022</td>
<td></td>
<td></td>
<td></td>
<td>Modelling 90th perc.</td>
<td>0.9</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>10/2020</td>
<td>Varnishing/Painting</td>
<td>180 min./shift</td>
<td>Inhalation</td>
<td>Measured (personal)</td>
<td>9.2</td>
<td>100</td>
</tr>
<tr>
<td>05/2021</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10.4</td>
<td></td>
</tr>
<tr>
<td>09/2022</td>
<td></td>
<td></td>
<td></td>
<td>Modelling 90th perc.</td>
<td>11.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>21</td>
<td></td>
</tr>
</tbody>
</table>
**3.2 Discussion**

The results of the measurements (static and personal) performed during the monitoring campaigns between 2020 and 2022 for the specific activities investigated are presented in Tables 1 and 2 in chapter 3.1. A comparison between the measured and modelled data can be made to allow a better understanding of the exposure pattern, and also the limitations and uncertainties of the modelling.

The results show that, in general, the modelled values are higher than the measured one, but modeled values smaller than the measured ones were also met in practice. This can be explained due to variabilities and limitations of the model. Most of uncertainties identified are coming from the selection of the input parameters and modifying factors entered into the model. The input parameters of the model may differ following the different perspective of the operator and this might introduce errors in selecting the right parameter. Therefore, the possibility to perform a site visit during activities is fundamental to obtain good-quality information [15].

The differences between measured and modelled data per each type of activity are presented in figures 4-6. In this particular case, the advantage was that the input parameters were in general known and adequate selected, due to the direct visit and access to information and workshop.
Fig. 4. Comparison between measured and modelled data for preparing activities

Fig. 5. Comparison between measured and modelled data for degreasing activities
It should be noted that chemical–physical properties of the chemical agents can play an important role in determining the result of an exposure estimate, potentially leading to errors in overestimation and underestimation of the exposure. One of these properties is volatility: previous studies outlined that exposure models can assume a different performance in terms of accuracy and precision according to the volatility of the chemical being considered [16, 17]. Anyway, a significant difference in the comparison of communicated and calculated exposure as a function of the volatility of the considered chemicals was not defined in the recent studies [15]. According to the previous published studies, ART provides most accurate and precise outcomes, with higher agreement between the predicted estimates and exposure measurements, but the model requires more detailed contextual information on the task-based exposure situation [18]. In general, ART is characterized by the tendency to overestimate especially low exposure levels, but some studies also documented underestimation in some scenarios, overall the model was found to be conservative, accurate and precise [15, 19].

4 Conclusion

The results of this study outlined the differences between measured (static and personal) and modelled data provided using ART 1.5 model. The differences occur mainly due to the inherent limitation and uncertainties of the modelling, and usually tend to overestimate the exposure, especially in case of low values.

The uncertainties of the modelled data could be reduced by adjusting the differences between the input parameters and the actual conditions in the workplaces. A visit to the respective workplace is recommended to allow an appropriate selection of the input parameters. This leads to an accurate estimate of the workers’ exposure related to organic solvents in the activities investigated, and also ensure the implementation of appropriate and effective operational conditions (OCs) and risk management measures (RMMs), following the hierarchy of control principles.
References

14. Government Decision no 1218/2006 laying down minimum requirements for the health and safety at work for the protection of workers from risks related of chemical agents