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# Pro-active Control of Atmospheric Emissions in Research and Small Labs. A Practical Criterion for the Design and Management of Activities under Hoods

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Environmental protection in research laboratories presents specific managerial problems strictly related to the fact that most of actual environmental managerial requirements are based on regulations tailored to relatively simple and continuous processes in manufacturing and service entities. In research labs the variety of substances used and the likelihood of creating new substances are generally higher than in industrial processes, while the quantity of substances is always significantly lower. Furthermore specific managerial criteria are necessary in order to take into account on one hand the variability of operations, on the other hand the impossibility to define in detail each operation. A practical criterion usable as decision making support for the organization of laboratory activities is presented in this work. The use of this criterion is aimed at obtaining the necessary authorizations from the competent authorities by ensuring, implicitly and preventively, the compliance with the regulatory threshold limits referred to the emissions in atmosphere. The first application of the methodology at University of Udine has permitted to derive some practical considerations in terms of environmental management that can be applied also in non academic research fields and in particular in small labs related to the process industry.

## 1. Introduction

The use of hazardous substances in process industrial plants, laboratories, etc., is strictly connected with environmental protection issues. Processes and activities may lead to hazardous substance releases in atmosphere, increasing air pollution.

Both European (EC Directive 84/360/EEC, 1984) and Italian (D.Lgs. 152/2006, 2006) regulations provide emission limit values for the emission points, in order to guarantee the environmental protection in case of emissions of hazardous substances. The emission limit values are established for different hazardous substances. Despite these regulations are tailored to stationary industrial plants, which are characterized by the use of large amounts of substances and by the presence of defined and generally continuous processes, they have to be applied also to research and small laboratories in which substances with carcinogen, mutagen, teratogen and reproductive hazard effects (R45, R46, R49, R60 and R61 substances) are used.

Otherwise than industrial plants, in research and small laboratories the operations carried out are not always the same, are not continuous and are performed at different operational locations, so it is difficult to identify a process to monitor and to which apply control measures in order to verify the

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compliance with emission limit values. Furthermore, the quantity of substances used is lower than in industrial process, while the number of different substances present and the possibility of creating new substances are generally higher.
Therefore, in order to comply with the environmental protection aims also during the laboratory activities and to define operative criteria that permit to deal with the emission limits values, it is useful to introduce a paradigm inversion in the management approach. Normally each operation performed is analysed in order to quantify the emissions (in terms of concentration, for example) and to verify the compliance with emission limit values. Due to the complexity of the activities carried out in small and research laboratories, it could be useful to operate backwards: starting from the emission limit value, the activity performed is managed in order to avoid to exceed such limit.
Obviously, this approach needs the adoption of suitable decision support tools for managing all the activities carried out in the laboratories. To permit a self organization of the laboratory operations these tools have to be user-friendly, that is easily to understand and implement.
This approach may guarantee the operative flexibility, fundamental in research activities, with the implicit compliance with emission limits provided by regulations.
In the following a decision support tool for the organization of laboratory activities, developed and adopted in the research laboratories at the University of Udine (I), is presented and described. The use of this tool is aimed at ensuring, implicitly and preventively, the compliance with regulatory threshold limits referred to the emissions in atmosphere.

## 2. Methodology

The decision support tool (DST) developed is aimed at providing research laboratory personnel with operative procedures for self-managing the research activities under hood in which hazardous substances are used. The final objective is to comply with emission limit values.
The DST in based on the concept that all the operations in laboratories have to be carried out without exceeding the emission limits established by Italian regulation (the emission limit values are expressed as grams per hour). This condition can be guaranteed in two ways:

1. The amount of hazardous substance used hourly is less than the threshold limit, even if the entire substance is released in the atmosphere;
2. The amount of hazardous substance used in an hour is more than the threshold limit but the substance released into the atmosphere is less than the threshold limit.

In the latter case it is necessary to introduce operational procedures to control the degree of substance dispersed in air and then to mitigate the amount of substance released into the atmosphere.
The procedures developed for the management of laboratory activities are related to different scenarios. Each scenario is defined on the basis of the characteristics of the hazardous substance used and on the typology of the activity carried out. It is supposed that all the activities are performed under laboratory hoods at ambient temperature and that all the substance released into air under the hood is conveyed by the hood system outdoor and released into the environment. Thus, the presence of filters and the substance deposition in the exhaust system are neglected (conservative approach).
The DST has been developed for substances at both liquid and solid (powders) states.
All the hazardous substances used are classified by using two criteria:

1. Threshold limits for each substance established by regulation (threshold class), Table 1;
2. Intrinsic emission into air of the substance (emission class), Tables 2 and 3.

The intrinsic emission $\varepsilon_L$ of liquids has been quantified according to Triolet and Sallé (2009) considering the vapour pressure of the liquid $P_v$ (Pa) and its molecular weight $M$ (g mol$^{-1}$):

$$\varepsilon_L = \left(\frac{M}{1000}\right)^{0.4} \cdot P_v \tag{1}$$

The intrinsic emission of powders has been quantified considering the dustiness of the materials.

*Table 1: Threshold classes for liquids and powders*

| Threshold limit[1] (g $h^{-1}$) | **Threshold class** |
|---|---|
| 0.5 | **0** |
| 1 | **1** |
| 5 | **2** |
| 10 | **3** |
| 25 | **4** |
| 50 | **5** |
| 100 | **6** |
| 300 | **7** |
| 2000 | **8** |
| 3000 | **9** |
| 4000 | **10** |

[1] established in D.Lgs. 152/2006 (2006).

*Table 2: Emission classes for liquids.*

| Emission limit (g $mol^{-1}$ Pa) | **Emission class** |
|---|---|
| $\varepsilon_L \leq 5$ | **$A_L$** |
| $5 < \varepsilon_L \leq 50$ | **$B_L$** |
| $50 < \varepsilon_L \leq 100$ | **$C_L$** |
| $100 < \varepsilon_L \leq 1000$ | **$D_L$** |
| $1000 < \varepsilon_L \leq 20000$ | **$E_L$** |
| $\varepsilon_L > 20000$ | **$F_L$** |

*Table 3: Emission classes for powders.*

| Dustiness of the material | **Emission class** |
|---|---|
| Little dust produced in handling | **$A_S$** |
| Some dust or vapour produced in handling | **$B_S$** |
| Dusty material | **$C_S$** |

This classification is aimed at establishing the maximum quantity of substance that can be dispersed in air during one hour of activity (Table 1) and at classifying the substance in terms of dispersion propensity in air (Tables 2 and 3). The quantity of substance that can be used depends also on the characteristics of the activity performed: high emission activities (like high pressure operations) tend to disperse more substance than low emission activities (like using dose-measuring devices). Therefore, in order to not exceed the emission limit values, when high emission activities are carried out, a less amount of substance has to be used or some mitigation measures has to be adopted. Furthermore, in order to consider the operational aspects, different procedures have been developed for liquids and solids.

**2.1 Procedures for liquid hazardous substances**

The evaporation rate $J$ (g $h^{-1}$) of a substance in liquid state is the main parameter to consider in order to estimate the propensity to dispersion in air of liquids. The evaporation rate $J$ can be obtained using the equation (Eq. 2) proposed by Triolet and Sallé (2009):

$$J = 3600\,\frac{22.01 \cdot S \cdot U \cdot \varepsilon_L}{P_{atm}} \qquad (2)$$

where $S$ is the evaporation surface ($m^2$), $U$ is the air velocity at the liquid surface (set equal to 0.7 m $s^{-1}$, the hood velocity), $\varepsilon_L$ is the intrinsic emission of the substance (as defined in Eq. 1) and $P_{atm}$

is the atmospheric pressure (Pa). Eq. 2 shows that the emission rate depends on the characteristics of the substance used ($\varepsilon_L$), on the surface of the liquid and on the characteristics of the laboratory hood (in terms of frontal air velocity). It is assumed that the hood is operative with a constant velocity of 0.7 m $s^{-1}$. Hence, for a given substance, $S$ is the factor that can be changed for mitigating the emission rate (and thus the dispersion in air of the substance). In order to develop operative procedures, two macro-activities have been considered: operations performed under the laboratory hood using an evaporating dish and operations performed under the laboratory hood without the use of an evaporating dish. These two operating configurations permit to estimate the maximum evaporation rate of the substance used and hence to define the maximum quantity of substance that can be used in order to respect the emission limit values. Figure 1 shows the DST abacus developed for liquid substances. The abacus shows the maximum amount of liquid substance usable during one hour of activities under laboratory hoods that implicitly guarantees the compliance with threshold limits. When the quantity is not specified, no restrictions are applied. If the threshold class and the emission class of a substance are known (Tables 1 and 2), it is possible to identify the type of activity that can be performed under the laboratory hood along with the maximum quantity of substance that can be used without exceeding the established emission limit values.

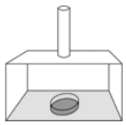
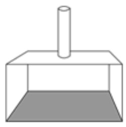
<table>
<tr><th rowspan="2">Activity</th><th rowspan="2">Threshold class</th><th colspan="6">Emission class</th></tr>
<tr><th>$A_L$</th><th>$B_L$</th><th>$C_L$</th><th>$D_L$</th><th>$E_L$</th><th>$F_L$</th></tr>
<tr><td rowspan="11"><br>Under laboratory hood with evaporating dish</td><td>0</td><td></td><td></td><td></td><td colspan="3">0.5 g</td></tr>
<tr><td>1</td><td></td><td></td><td></td><td colspan="3">1 g</td></tr>
<tr><td>2</td><td></td><td></td><td></td><td></td><td colspan="2">5 g</td></tr>
<tr><td>3</td><td></td><td></td><td></td><td></td><td colspan="2">10 g</td></tr>
<tr><td>4</td><td></td><td></td><td></td><td></td><td colspan="2">25 g</td></tr>
<tr><td>5</td><td></td><td></td><td></td><td></td><td colspan="2">50 g</td></tr>
<tr><td>6</td><td></td><td></td><td></td><td></td><td></td><td>100 g</td></tr>
<tr><td>7</td><td></td><td></td><td></td><td></td><td></td><td>300 g</td></tr>
<tr><td>8</td><td></td><td></td><td></td><td></td><td></td><td>2 kg</td></tr>
<tr><td>9</td><td></td><td></td><td></td><td></td><td></td><td>3 kg</td></tr>
<tr><td>10</td><td></td><td></td><td></td><td></td><td></td><td>4 kg</td></tr>
<tr><td rowspan="11"><br>Under laboratory hood</td><td>0</td><td colspan="6">0.5 g</td></tr>
<tr><td>1</td><td colspan="6">1 g</td></tr>
<tr><td>2</td><td></td><td colspan="5">5 g</td></tr>
<tr><td>3</td><td></td><td colspan="5">10 g</td></tr>
<tr><td>4</td><td></td><td colspan="5">25 g</td></tr>
<tr><td>5</td><td></td><td></td><td colspan="4">50 g</td></tr>
<tr><td>6</td><td></td><td></td><td></td><td colspan="3">100 g</td></tr>
<tr><td>7</td><td></td><td></td><td></td><td colspan="3">300 g</td></tr>
<tr><td>8</td><td></td><td></td><td></td><td></td><td colspan="2">2 kg</td></tr>
<tr><td>9</td><td></td><td></td><td></td><td></td><td colspan="2">3 kg</td></tr>
<tr><td>10</td><td></td><td></td><td></td><td></td><td colspan="2">4 kg</td></tr>
</table>

*Figure 1: DST abacus for liquids*

**2.2 Procedures for hazardous powders**

The dispersion propensity in air of powders is related to their dustiness. Furthermore, the amount of substance dispersed in air depends also on how the substance is handled, that is on the type of activity performed. These two aspects have been considered for estimating the amount of powders released in air during activities carried out under laboratory hoods. The methodology proposed by Cherrie and Schneider (1999), also adopted in Marquart et al. (2008), has been used to quantify the maximum substance $m$ that can be used in different research activities without exceeding the emission limit values:

$$m \le m_{ref}\ \left[\varepsilon_S \cdot h\left(1-\eta_{lv}\right)\right]t_a \qquad (3)$$

$m$ is the maximum amount of hazardous powder (g) that can be used during the time of activity $t_a$ (expressed as hours), $m_{ref}$ is the threshold limit (Table 1), $\varepsilon_s$ is the intrinsic emissivity of the powder and depends on the emission class (Table 3), $h$ is a factor used to include the method of handling or processing the substance, $(1- \eta_{lv})$ includes the efficiency of local controls, such as ventilation (set conservatively equal to 1). All the scores for $\varepsilon_s$ and $h$ are reported in Cherrie and Schneider (1999). The DST abacus developed for the powders is illustrated in Figure 2. The maximum amount of substance that can be used hourly in different activities without exceeding the threshold limits can be easily obtained once the threshold class (Table 1) and the emission class for powders (Table 3) are known.

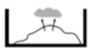
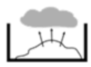
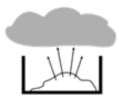
| Activity | Threshold class | Emission class $A_s$ | $B_s$ | $C_s$ |
|---|---|---|---|---|
|  Weighting, pouring, etc. | 0 | 5 g | 1.5 g | 0.5 g |
| | 1 | 10 g | 3 g | 1 g |
| | 2 | 50 g | 15 g | 5 g |
| | 3 | 100 g | 30 g | 10 g |
| | 4 | 250 g | 75 g | 25 g |
| | 5 | 500 g | 150 g | 50 g |
| | 6 | 1 kg | 300 g | 100 g |
| | 7 | 3 kg | 1 kg | 300 g |
| | 8 | 20 kg | 6 kg | 2 kg |
| | 9 | 30 kg | 10 kg | 3 kg |
| | 10 | 40 kg | 13 kg | 4 kg |
|  Dropping less than 0.5 m, pouring with splashing, etc. | 0 | 1.5 g | 0.5 g | |
| | 1 | 3 g | 1 g | |
| | 2 | 15 g | 5 g | |
| | 3 | 30 g | 10 g | |
| | 4 | 75 g | 25 g | |
| | 5 | 150 g | 50 g | |
| | 6 | 300 g | 100 g | |
| | 7 | 1 kg | 300 g | |
| | 8 | 6 kg | 2 kg | |
| | 9 | 10 kg | 3 kg | |
| | 10 | 13 kg | 4 kg | |
|  Dropping more than 0.5 m, manual sawing, mixing products with a mixer, etc. | 0 | 0.5 g | | |
| | 1 | 1 g | | |
| | 2 | 5 g | | |
| | 3 | 10 g | | |
| | 4 | 25 g | | |
| | 5 | 50 g | | |
| | 6 | 100 g | | |
| | 7 | 300 g | | |
| | 8 | 2 kg | | |
| | 9 | 3 kg | | |
| | 10 | 4 kg | | |

*Figure 2: DST abacus for powders*

## 3. Discussion

The use of the decision support tools shown in Figures 1 and 2 permits to organize activities in research laboratories in a flexible way. Thanks to its simple and user-friendly configuration, the DST abacus can be used by personnel both to estimate the amount of substance usable, and to organize its activity, guaranteeing the compliance with emission limits. Firstly, the threshold class of the substance used (Table 1) has to be identified. National regulations (in Italy D.Lgs. 152/2006, 2006) provide threshold limits for different substances. Once the characteristics of the substance are known (vapour pressure and molecular weight for liquids, dustiness characteristics for powders), the emission class for the substance is obtained (Tables 2 and 3). Finally, if the type of activity that has to be carried out is identified, the maximum amount of substance usable without exceeding the emission limit values can

be easily estimated. On the contrary, if during the activity the use of a fixed amount of substance is fundamental, it is possible to set the operations to guarantee the respect of the maximum quantity of substance dispersed in air.
Besides its use as operative tool, the DST abacus can also be used to manage more activities carried out at the same time at one emission point (for example simultaneous use of more hoods with the same exhaust evacuation system) compatibly with the emission limits. Finally, if the activities to be performed in the laboratories are known, the criteria proposed can be adopted for designing the layout of hoods and the location of emission points, guaranteeing environmental protection.
The proposed DST is currently adopted at the University of Udine. Its adoption permitted to obtain the necessary authorizations by the competent authorities to use hazardous substances in research laboratories.

## 4. Conclusion

The peculiarity of the activities carried out in research and small laboratories (not defined and discontinuous processes, small amount of substances used, high number of different substances present, creation of new chemical products, etc.) make difficult to implement traditional methods usable to control emissions of hazardous substances into atmosphere (generally tailored to processes at industrial plant scale). In order to deal with these issues, a paradigm inversion has been adopted: to develop flexible and self-managing procedures which can be easily implemented by laboratory personnel and which implicitly guarantee the respect of environmental protection requirements (emission limits).
In this work a decision support tool based on abacus, usable for organizing activities under hoods in small and research laboratories, has been proposed. It permits to estimate in a simple and rapid way the amount of hazardous substance usable without exceeding the emission limit values once the regulation requirements for the substance used and its physical characteristics are known. Due to its simplicity and a user-friendly interface, the management of research activities using hazardous substances with the implicit respect of environmental issues is possible. Besides its use in laboratories, the criteria adopted in the decision support tool may be proposed to the competent authorities as monitoring alternative to the detailed description of the processes, impracticable in research and small laboratories.
Currently the procedures are used by the University of Udine in activities carried out at ambient temperature. Considering the positive results obtained, the procedures are going to be adopted also to manage high temperature activities.

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