LCA and an Integrated Environmental Monitoring System as joint tools for incinerator environmental impact assessment

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Abstract

Incinerator emissions still represent an important issue of public environmental concern. The application of Life Cycle Assessment to a municipal solid waste (MSW) incinerator is an important instrument for the identification of the main environmental impacts on the entire ecosystem. Beside this, an Integrated Environmental Monitoring System can be applied in order to understand the most direct contamination in the surrounding territory. This approach can integrate ordinary chemical monitoring instruments, together with biomonitoring methodologies, and can give an interesting understanding of the interaction of the various pollutants with the environmental matrices. The application of both tools provided useful results: by using LCA it was possible to understand that the incineration process, besides reducing the amount of waste which must be landfilled, decreases the environmental impact related to some categories, due to energy recovery which avoids the consumption of non-renewable fuels; by monitoring, many interesting correlations were found between heavy metals (chosen as environmental indicators) both in gas emissions and in natural matrices in the surroundings (in particular, depositions). The joint employment of these two instruments can lead researchers and decision makers to understand the most critical steps of the whole incineration process, indicating the greatest global, regional environmental and local impacts.

Keywords: incineration plants, heavy metals, Life Cycle Assessment, environmental monitoring, environmental impact.
1 Introduction

The influence of waste incineration on the environment and in particular on public health is a widely debated subject in the framework of an Integrated Waste Management System (Hester and Harrison [1]).

In recent years, the implementation of modern abatement techniques in order to reduce the pollutant emissions from the stack, greatly contained the potential hazard related to incineration plants. Furthermore, in Italy as in other European Countries, electric or thermal energy recovery is now prescribed by law, and then, in a life cycle prospective, their environmental impact can be compared to that of ordinary power plants.

Life Cycle Assessment (LCA) is a methodological tool based on a global vision of the production system, in which all the processes and the operations, from the extraction of raw materials to the end of life, are analysed in terms of input and output. The LCA applied to MSW integrated management constitutes a relatively new field of application of the methodology, and introduces great potentialities of development, especially in support to decision makers and the companies that manage the services of waste collection, transport and recycling/disposal.

Even if it is typically treated a step of any product LCA, waste management can be considered as an independent system [2], whose input streams are the rejects from human and production activities and whose outputs are the final emissions into the environment (solid, liquid and gaseous) and the new useful products (recycled materials, energy, compost) [3].

A process of incineration, in particular, produces an environmental impact, due to the emitted pollutants, directly (from the stack, from bottom or fly ashes) or indirectly (due to the building of the plant and its operational activities); however, an “avoided impact” have to be considered, which is connected to the avoided consumption of non-renewable fuels and eventually to the material recovery resulting by the possible recycling of bottom ash [4].

However, the more remarkable environmental impact is produced by the gaseous emissions and the major pollutant deposition is limited to a confined zone near the plant. Thus, many studies focused on the investigation of the environmental matrixes in the most invested area [5,6,7,8].

The Integrated Environmental Monitoring System approach [9] starts choosing opportune Environmental Indicators, such as the heavy metals, continues characterising the source of contamination and sampling and analysing the more meaningful environmental receptors, and finishes investigating the relationship of cause-effect between emissions and environmental concentration, even through statistic tools of multivariate analysis [8].

2 Experimental

2.1 Life Cycle Assessment

LCA has been applied to the case of an incineration plant in Northern Italy, burning about 160000 t/y of urban waste and producing about 75*106 MJ/year.
of electric energy. It produces about 8.5 t of wet flue gas, 25 Kg of fly ash and 300 Kg of bottom ash per tonne of burnt waste.

The LCA software employed was TEAM (Ecobilan, France). Named step 1 the overall impact due to the process of incineration, the single phases in which it was divided were: Erection and demolition of the plant (step 2), Direct impact (3), Transport and disposal of bottom ash (4), Energy recovery (5), Disposal of fly ash (6), Energy production (7), Gas cleaning (8), General pre-treatment (9), Waste water treatment (10).

The resulting global balance is performed for each category in which environmental impact is divided (Air acidification, Eutrophication, Depletion of non renewable resources, Global warming, Aquatic ecotoxicity, Terrestrial ecotoxicity, Sediment ecotoxicity, Human toxicity, Photochemical oxidant formation, Ozone depletion). It could result greater than zero, indicating a positive environmental impact, or less than zero, showing an avoided impact, thanks to the recovery of energy.

2.2 Integrated Environmental Monitoring System

The environmental monitoring was initially performed by sampling and analysing soil and plants in many places all around the plant [10]. A more guided monitoring plan was then carried out, according to the results given by the mathematical models of contaminant deposition ISC3 (U.S. Environmental Protection Agency). Five monitoring sites were chosen in the areas most invested by incinerator pollutant fallout, while a sixth was placed quite far from the plant, in the direction of minimum dispersion. In these sites, surface soil was sampled.

Three wet&dry samplers for atmospheric depositions were placed since June 2000 in two sites of maximum fallout and a third in the most distant site from the plant, to compare the different heavy metal flows in the zones of higher and lower deposition of particulate emitted from incineration plant. All the procedures for the collection, treatment and analysis of heavy metals in gas emissions and natural samples were described elsewhere [8], together with the tests of recovery by means of Certified Reference Materials.

Data elaboration was performed by applying a Principal Component Analysis to the variable content (heavy metals) in all industrial and environmental samples (gas emission, soil, atmospheric deposition). Q-PARVUS 3.0 software was employed.

3 Results and discussion

3.1 Impact assessment by LCA

Emission factors of pollutants and other chemical parameters in stack emissions are reported in Table 1 (referring to 2003).

Impact assessment results are presented in Figure 1: for every single category, the balance of the environmental impact of the process of incineration is
depicted, obtained adding positive and negative contributions of the different steps. Negative contribution are obtained by comparison with the environmental impact due to a power plant, considering the energetic mix used in Italy, for the same quantity of energy produced.

Table 1: Emission fluxes of different parameters in gas emission from incinerator.

<table>
<thead>
<tr>
<th></th>
<th>SO\textsubscript{x}</th>
<th>NO\textsubscript{x}</th>
<th>CO</th>
<th>HCl</th>
<th>HF</th>
<th>NH\textsubscript{3}</th>
<th>Cd</th>
<th>As</th>
<th>Co</th>
<th>Hg</th>
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<tr>
<td>kg/y</td>
<td>2400</td>
<td>170</td>
<td>1400</td>
<td>5800</td>
<td>320</td>
<td>1600</td>
<td>0.34</td>
<td>0.51</td>
<td>0.93</td>
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<table>
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<tr>
<th></th>
<th>Mn</th>
<th>Pb</th>
<th>Cr</th>
<th>Ni</th>
<th>Zn</th>
<th>Cu</th>
<th>PCDD</th>
<th>PCB</th>
<th>IPA</th>
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<td>kg/y</td>
<td>3.4</td>
<td>43</td>
<td>13</td>
<td>1.8</td>
<td>51</td>
<td>7.5</td>
<td>34</td>
<td>20</td>
<td>79</td>
<td>2.2</td>
</tr>
</tbody>
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Figure 1: Impact categories contribution (>0: positive impact; <0: avoided impact). For each impact category, different units are used, indicated above or below the bars.

The highest positive impact (Global warming) is shown in Figure 2, the highest negative (avoided) impact (Aquatic ecotoxicity) in Figure 3.

It can be deduce that the evaluation of the global environmental impact produced by an incineration plant is the result of a complex calculation of all the anthropic activities related to this process and is strongly tied to the type of environmental effect that is wanted to be considered. In this case, avoided impacts were observed in 7 out of the 10 environmental impact categories considered, due to the production of electrical energy from the heat of combustion.

However, further impact reductions could be achieved if:

a) the fraction of thermal energy not converted in electric energy is recovered, for instance in a possible plant of district heating for the civil residences;
b) the bottom ash is recovered and, after sieving and inertisation processes, used as filling material in road bases or for other uses in building industry [11].

Figure 2: Example of a globally positive impact: greenhouse effect. The major contributions on the global balance (first histogram bar) are due to the process direct impact (step 3) and the avoided impact due to energy recovery (step 5).

Figure 3: Example of a globally avoided impact: aquatic ecotoxicity. The major contribution on the global balance (first histogram bar) is due to the avoided impact due to energy recovery (step 5), while the major processes which provide positive impacts are the production of bottom ash (step 4) and of toxic waste (step 6).
3.2 Integrated Environmental Monitoring System

Figure 4: Biplot of the first two factors of heavy metal concentration in gas emission from the incinerator.

Figure 5: Biplot of the first two Factors of heavy metal fluxes in atmospheric depositions collected by a sampler in a maximum fallout site.

Figure 4 shows the results of a Factor Analysis (obtained after a Varimax rotation of the first three Principal Components) applied to the data of heavy metal concentration in gas emission samples from incinerator stacks. Four major
components resulted: the first is given by Cr, Cu, Mn and Ni, which are also particularly well correlated, the second is represented especially by Pb and Zn, while the third and the fourth are mainly related with Hg and Cd respectively.

The most important correspondence of these correlation could be seen in wet and dry deposition in the site of predicted maximum fallout of pollutants from incinerator. In Figure 5 an analogous Factor Analysis biplot graph is represented, applied to total heavy metal fluxes collected in atmospheric deposition. Also in this case, Cr, Cu, Mn and Ni lie on the first factor, while on the second Zn gives a major contribution (here with Hg) and Cd is again on the fourth factor. On the third, unlike emission factor analysis, Pb can be found, probably associated also to vehicular traffic.

The results are significantly different for the deposition sampler sited far from the plant. In this case, as plotted in Figure 6, Factor Analysis gave quite different variable pattern, likely due to other sources rather than incinerator.

Figure 6: Biplot of the first two Factors of heavy metal fluxes in atmospheric depositions collected by a sampler in a minimum fallout site.

4 Conclusion

Two different tools were jointly used for a thorough assessment of environmental impact due to an incineration plant: Life Cycle Assessment and Integrated Environmental Monitoring System.

The former has been employed as an useful approach, to become aware of the most important indicators of the incineration process impact. Furthermore, it can give important information about the sustainability of a process, compared to a set of other alternative activities, in particular in the application to waste
management. In the case study here presented, the environmental impact of many categories resulted negative (which means avoided) due to the energy produced without using non-renewable resources, as in power plants.

The latter tool is adopted to understand the most direct impact in the surrounding of the plant. Heavy metals were chosen as environmental tracers of incinerator contamination. A dependence on the distance was found, in particular in depositions and for those metals which are not involved in other important contamination processes (e.g. Pb, also due to vehicular traffic). The multivariate statistical analysis showed interesting similarities in the data dispersion, both in process and in natural matrices, and similar pattern in variable (heavy metal) distribution.

References
