Environmental Damage Assessment Applied to Process Analysis. A Decision Support Alternative

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Abstract: Nowadays the environmental studies are increasingly important in the process analysis and design. These studies not only can be used to quantify the environmental damage, but also, as optimisation criteria together with technical and economical evaluations. In the present study, we develop a methodology based on several techniques (Risk Assessment (RA), Design Support Framework (DSF), and Endpoints Indicators Applying). This methodology which links the main aspects of process analysis and environmental damage assessment, comprehends three main steps: the first one involves the accomplishment of an inventory of raw material and energetic streams, which may be predicted or computed depending on the process to be analysed. The second step is developed the evaluation of environmental impacts. In this frame, an eco-vector is used to quantify the environmental loads from the inventory data. This procedure is completed by the application of models to impact prediction on human health, natural resources and the ecosystem. The last one, transforms environmental impacts in damage indicators by using of weighting methods. The referred methodology has been validated in a fully automated and controlled pilot plant. The developed case study has allowed comparing the different types of loads in a separation process and their environmental contribution to each step.

Keywords: Environmental Analysis; Damage Prediction Tools; Process Analysis, Damage Assessment and Process Design Integration

1. INTRODUCTION

The modern stile of strategic management applied nowadays in the project of new processes and products establishes two general levels of actions: tactical and operational. The tactical level embraces structural actions, as determination of the product's features, selections of raw material and its suppliers, choosing of technology, definition of the conceptual design of process, and market share. Decisions like these reflexes over the actions of the operational level, where executive proceeding as process management, logistics of resources and products, communication and marketing are object of discussion.

The unmistakable necessity of considers, additionally to this scenario, the environmental impacts produced by a future installation increases the level of difficulty at which are subjected the decision-makers.

Seeking to reduce the inherent grade of uncertainty and subjectivity related to the theme, several support techniques have been proposed; amongst them, must be highlighted by they applicability and consistence the methodologies of Life Cycle Assessment (LCA) and Environmental Damage Assessment (EDA).

The LCA is a fairly new chain-orientated tool created to evaluate the environmental performance of a product, since the extraction of raw materials, passing by the manufacturing and use, until its final disposal, where use to be concluded the life cycle of it.

The methodology of LCA can be divided in four steps: Goal and Scope Definition, Inventory Analysis, Impact Assessment and Interpretation. Through all of these steps, environmental aspects regarded to consumptions of natural resource and releases to air, water and soil, are identified, quantified and expressed in terms impact indicators providing to the decision makers, the environmental profile of the process in study. By its own features, LCA helps to uncover vulnerable points in the life cycle of a product using to do it, the logical process of comparison with other alternatives. According this approach is possible to consider this methodology as an instrument of information and planning.

To realise a secure decision-making process is still important knowing the effects promoted by the new installation over the environment. The application of the technique of Environmental Damage Assessment (EDA) can supply this necessity, furnishing consistent information about it, al level of damage.

There are many ways to realise an EDA, being that one of the most traditional of them is by using the Eco-indicator99 methodology. Based on cause-effect relationships, this methodology is able to traduce in terms of health effects, the release of a contaminant. To do it so, the Eco-indicator99 embraces the following steps: *fate analysis*, *exposure analysis*, *effect analys*is, and damage analysis.

This present paper proposes a methodology that permits introducing the environmental concerns in the process analysis during the decision-making step, by the on-line prediction of environmental damage for different scenarios of study. Section 2 presents the followed methodology and study focus. Its application developed to a separation process, which where realised in a fully automated and controlled pilot plan, is presented in Section 3. Finally, in the Section 4 are presented the main results obtained in terms of damages, and its incidence in the process analysis.

2. METHODOLOGY'S FRAMEWORK

The integration between the process analysis and the environmental assessment is the object of the methodology developed in this work. The methodology comprises the steps of process modelling, transference information, evaluation of the environmental damage, and analysis of the environmental viability, all of them, arranged as presented in Figure 1. A short description of the actions concerned to each of the steps is presented as following.

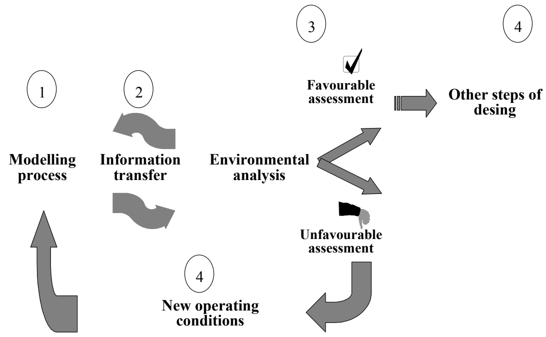

Figure 1. General description of the methodology

2. 1 Process modelling by plant data

The first step of the methodology consists on the LCI establishment, which must be obtained by modelling the system. The objective of this procedure is to quantify consumption of resources and releases to the environment as close as possible to the real operation conditions.

The option by using modelling programs to build up the LCI is based on its capability to predict parameters and conditions of process in a secure and fast way; this feature makes possible either the design of new process or the optimisation of existing installations, both with acceptably performance grade. Nevertheless, the level of available information to do it limits the range of actuation of these tools, what makes obligatory a validation procedure in order to give accurate results.

2.2 Information transfer between tools

The connection between two computational tools is possible due to the development of utilities of programming which allow export and import data using spreadsheets as interfaces [Herrera, 2001]. The bridges necessaries to make it can be build up through programming macros resource, which captures data from an application, and sending it to a specific site located on other one.

In the new application, the data can be treated either to generate results, or transformed to be used in a new application.

2.3 Environmental damage

In this stage, the effects caused by the process over the environment are quantified. Actually, a great number of methodologies can be applied successfully. In particular, the consistence of results produced by the use of the Eco-Matrix must be highlighted [Sonneman, 2002].

An Eco-Matrix is an algorithm composed by multidimensional vectors called eco-vectors [Castells, 2000]. An eco-vector, by it turns, consists of mathematical operators which composition depends on the Environmental Loads (EL). Each process stream has associated an eco-vector whose elements are expressed in environmental loads per functional unit (EL/FU).

2.4 Process analysis or environmental feasibility

The last stage of the methodology comprises the evaluation of the environmental feasibility of the system, which is developed by comparing the generated environmental damage. As this analysis uses an exhaustive process, and considering that the process of decision-making depends on its results, the definition of a criterion of selection can be a helpful support tool in order to determine the best environmental alternative.

3. CASE STUDY

3.1 Process description

In order to apply the proposed methodology, the separation of ethanol-water by distillation was chosen as case study. The system consists on a distillation packed column device fully automated, where the preparation of the feed solution, start-up and continuous operations can be grasped. As condenser, an air cooler is used.

Considering that the plant requires electric power and steam, which production consume natural resources and generates releases to the environment, the system in study comprises not only the distillation process, but also units of production of its utilities. In Figure 2 an outline of the system is presented.

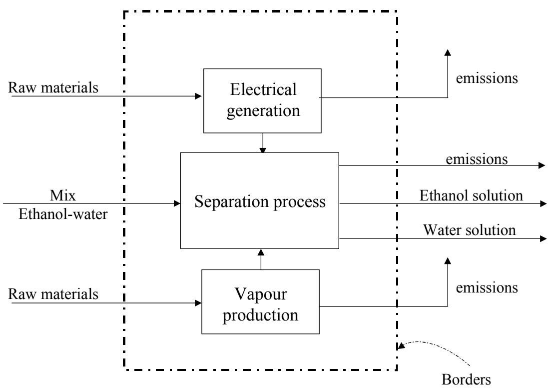

Figure 2. Boundaries of the system

3.2 Process modelling

The dynamic simulation modelling was made using *Hysys.Plant®* tool [AEA Technology, Calgary, Canada].

The results generated by the simulation were transferred to a spreadsheet (*Microsoft® Excel*), through macros, programmed in Visual Basic. Information such as pressure, temperature, flow and composition of the streams were displayed and logout; furthermore, the energy consumptions (both electricity for pumping, and condensing, and heating) were computed by the simulation.

3.3 Environmental analysis of the case study

In order to assess the environmental damage of the process, three steps, were developed: *definition of the eco-vector*, *determination of scenarios* and application of *the damage assessment method.*

The eco-vector definition requires the assignment of environmental loads (EL); in this sense, sulphur dioxide (SO_2), carbon dioxide (CO_2), and nitrogen oxides (NOx) were chosen as Environmental Load (EL), taking into account their relevance in the main environmental effects. The information related with these loads were provided by two bibliographic sources: *ETH Report* [Frischknecht, 1996], and *TEAM™ database* [Ecobilan Group, 1998]. Plant data regarding to the raw material and energy consumption has also been used.

The use of scenarios allows comparing different alternatives in terms of systems environments interaction. In this sense, two scenarios were chosen, based on the several possibilities to obtain the steam and electricity required in this process.

The steam was defined as obtained through natural gas combustion, and the electricity was considered by two alternatives: natural gas combustion and coal combustion. The chosen scenarios are shown in Table 1.

Table 1. Elected scenarios.

Scenario	Description
1	Steam and Electricity Production*: Natural Gas Combustion*
2	Steam Production: *Natural Gas Combustion* Electricity Production: *Coal Combustion*

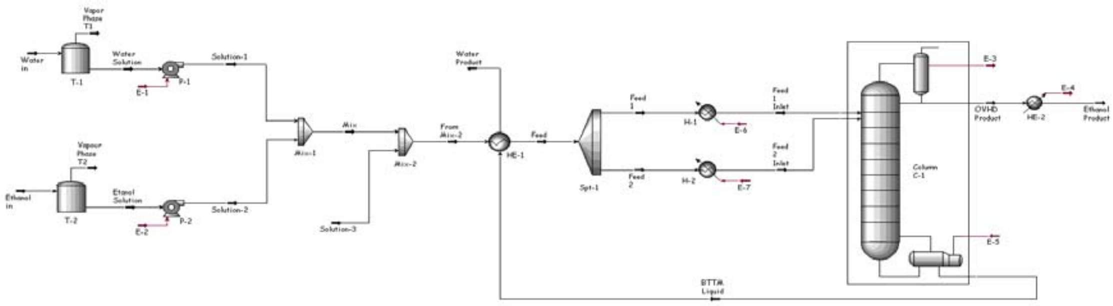

Figure 5. Process Flow Diagram of the separation process model

The environmental damage was assessed applying a damage-oriented method. A complex cause-effect chain was performed in order to link the LCI results – through impact categories – with three damage categories: *human health*, *ecosystem quality* and *resources*.

As well as the fate, effect, exposure and damage assessment, the model is able to document uncertainties, maintaining a certain scientific validation.

4. RESULTS

4.1 Model of the separation process

Figure 5 illustrates the process flow of the separation process model. A summary of the main production results is presented in Table 2.

Table 2. Production data of the separation process.

Main Streams	
Produced ethanol (Ton/yr)	463,6
Feed mix (Ton/yr)	1234
Required energy (TJ/yr	153
Working hours per year (h)	8.280

4.2 Information transfer

The information transfer between the simulation model and the environmental analysis was made using a spreadsheet as interface. Then, it was possible to assess the process behaviour in terms of several variables. When the results of the modelling allow a general understanding of the process, the improvement brought by the use of the interface, (which make possible to change the operational data on-line) must be highlighted. The transferred information is shown in Table 3.

Table 3. Transferred information.

Transferred Variables	
Feed (kg/h)	149
Water (kg/h)	93,01
Ethanol (kg/h)	55,99
Energy (MJ/kg Feed)	12,72

4.3 Environmental damage evaluation

The first aspect used to assess the environmental damage is to compute the eco-vector. In this case, it was expressed in terms of *tonne of feed mix*. Tables 4 and 5 show the eco-vector for the two scenarios.

Table 4. Eco-vector scenario 1

EL	**Vapour**	**Electricity**	**Total Emissions**
	kg /kg Feed	kg /kg Feed	Ton /yr
CO_2	196,065	293,865	4,06E+03
NOx	0,099	0,634	6,07
SO_2	0,047	1,806	15,3

Table 5. Eco-vector scenario 2

EL	**Vapour**	**Electricity**	**Total Emissions**
	kg /kg Feed	kg /kg Feed	Ton /yr
CO_2	196,1	228,3	3,51E+03
NOx	0,10	0,55	5,40
SO_2	0,05	1,24	10,70

The damage-oriented method uses different procedures to establish the linkage between the inventory table and the potential damages.

In the model for Human Health Impact four steps have been used:
a) Fate analysis, linking the emission (expressed as mass) to a temporary change in concentration.
b) Exposure analysis, linking this temporary concentration to a dose.
c) Effect analysis, linking the dose to a number of health effects, like the number and types of cancers, or the respiratory effects.
d) Damage analysis, links health effects to the number of Years Lived Disabled (YLD) and Years of Life Lost (YLL).

For ecosystem health two different approaches are used:
a) Toxic emissions and emissions that change acidity and nutrients levels go through the procedure of:
- i) Fate analysis, linking emissions to concentrations
- ii) Effect analysis, linking concentrations to toxic stress or increased nutrient or acidity levels.
- iii) Damage analysis, linking these effects to the increased potentially disappeared fraction for plants.

b) Land-use and land transformation is modelled by empirical data on the quality of ecosystems, as a function of the land-use and the area size.

Three damage categories were selected in order to relate the environmental loads with the effect and finally, to calculate the damage. The categories were: C*limate Change, Respiratory Effects* and A*cidification.* On the other hand, the chosen damages were *Human Health* and *Ecosystem Quality*.

In order to give clarity to methodology, Figure 4 shows damage categories and the related damages.

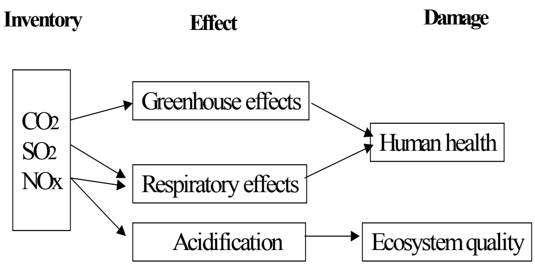

Figure 4. Damage assessment methodology

The damage evaluation was made by computational software that support the assessment of priority impacts resulting from the exposure to airborne pollutants [Ecosense version 2.0 ©. 1997]. The model assesses the damage through factors for each category. Table 6 shows the damage factor used related with each load. The total damage for each scenario is presented in Table 7.

Table 6. Damage factor by load and category.

	Damage factor		
	Human health		Ecosystem
EL	**Respirator Effects**	**Climate change**	**Acidification /Eutrophication**
CO_2	-	5,45E-03	-
NOx	1,42	-	8,12E-02
SO_2	2,30	1,79	4,45E-03

Table 7. Total damage assessed for load.

	Damage total	
EL	**Scenario 1**	**Scenario 2**
CO_2	22,1	19,2
NOx	24,9	43,7
SO_2	23	81,1

4.4 Environmental viability of the separation process

The decision making in the process analysis is a task that involves all the life cycle stages of a product. As the project progresses, the number of alternatives will be reduced by the use of screening tools, until the final design and revising cycles. As the number of alternatives is reduced, the design is more detailed. This progressive articulation of detail is accompanied by a reduction in uncertainty, and often moves the decision making exercise from a discrete option-evaluation exercise, to one where a preferred operating environment for a particular alternative is sought.

In the case of an experimental ethanol-water separation process, the total damage is very similar for both scenarios; however, the scenario 2 has a minor damage.

This result allows following the process design and focuses the attention in the next steps of the process, for instances, how to improve the electrical generation through the coal combustion.

5. CONCLUSIONS

Although significant progress are taken place to integrate environmental aspects with technical and economic ones in the decision making tasks, some limitations related to the uncertainty of the data proved by the environmental tools still exist. In this sense, the proposed methodology is an efficient support tool in the decision making, due to the possibility to assess and prevent the environmental impacts in the processes and product in a friendly way.

The resource of programming of macros has a decisive paper in this methodology, since it allows that a process simulator operates compatible and simultaneously with an interface or spreadsheet.

Although the methodology was applied to a very simple process, the results show its capability to integrate several tools, not only to increase the account of available information in the making decision step, but also even to decrease the uncertainty of the data.

Regarding to the case study, two conclusions can be highlighted:

a) The atmospheric emissions produce almost the same impacts and damages in both of scenarios, what reasonable as the *Particulate Matter* was not considered in the composition of the eco-vector; and

b) The use of the electricity self-generated allows decrease the total damage.

6. ACKNOWLEDGEMENTS

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