# WASTE REDUCTION IN THE CHEMICAL INDUSTRY: A TWO LEVEL PROBLEM

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The waste minimisation in the chemical industry has shifted from the end-of-pipe treatment to the elimination of wastes at the source as well as environmentally sound internal recycling. Several systematic strategies based on the hierarchical process design have been developed and used in the practice. In the case of a chemical company that consists of several processes or plants it is necessary to co-ordinate the waste minimisation incentives on the company level. The main goal is to utilise the waste of a plant in another plant that is to design closed-cycle processing. This article describes a systematic two level procedure for the reduction of the global emission of a chemical company.

## Introduction

The chemical processes are possible sources of the pollution of the environment. There can be produced such kind of by-products that are waste, sometimes hazardous waste. Besides the raw material usually significant amount of energy is also needed. In the broadest sense, a waste is any material or energy input of a process that does not become incorporated into the desired final product(s). In this manner the chemical processes represent double pollution to the environment. As a result of increased environmental awareness and regulations, the emphasis of environmental protection has shifted from the end-of-pipe treatment to the reduction or elimination of wastes at the source as well as environmentally sound internal recycling.


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The waste management hierarchy defined by EPA (US Environmental Protection Agency) ranks pollution prevention at the top *(1)*. The hierarchy is: • *source reduction,* • *recycling,* • *waste separation and concentration,* • *energy and material recovery,* • *waste treatment,* • *disposal,* respectively. The source reduction has also an economic advantage, since it reduces or eliminates the burden upon the later steps of the technology, such as waste treatment. Switching the emphasis from waste treatment to waste minimisation requires a new approach to plant design and operation. It is a heuristic rule that incorporating waste elimination during plant design is less complicated than modifying operations at an existing plant. However, it happens frequently that an existing plant is to be improved so that it satisfies the new increased environmental regulations.

In the case of a chemical company, which includes more chemical processes or plants, for efficient global waste minimisation and elimination it is still not enough to study and develop individually the several processes. The improvements at the different processes are to be investigated and co-ordinated on the second level, on the company level and it also necessary to study together the processes to eliminate the waste emission of the company.

## Waste minimisation on the process level

The developments of process improvements to reduce emission has historically been accomplished on an ad hoc basis by creative engineers. This generation of waste minimisation focuses on good housekeeping practices, inventory control and minor changes in operation practices.

Even more rapid progress is possible if systematic techniques are used to identify process improvement opportunities. Such kinds of techniques have been already developed for chemical plants by Douglas *(2)* and Smith and Petela *(3)*.

The basis of these systematic strategies is the hierarchical approach for chemical process synthesis. Douglas *(4)* has proposed a hierarchical procedure where heuristic rules are used to guide search directions to overcome the need to examine all possible structures in order to find a small number of near-optimal arrangements. Recently, Douglas *(2)* has slightly modified his hierarchical procedure with the objective of reducing emissions (Table 1).

Table 1

*Hierarchical procedure for process synthesis (2)*

| | |
|---|---|
| 1. | Input information: type of the problem |
| 2. | Input - output structure of the flowsheet |
| 3. | recycle structure of the flowsheet |
| 4. | specification of the separation system |
| 4a. | general structure: phase splits |
| 4b. | vapour recovery system |
| 4c. | liquid recovery system |
| 4d. | solid recovery system |
| 5. | energy integration |
| 6. | evaluation of alternatives |
| 7. | flexibility and control |
| 8. | safety |

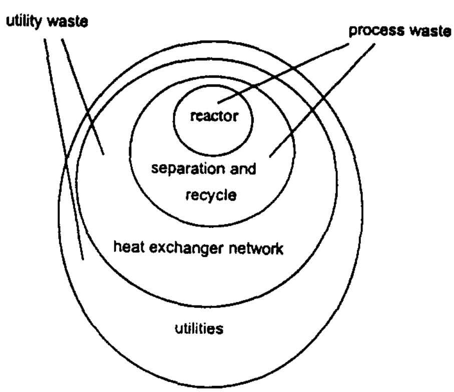


Figure 1. The *onion diagram* for process design *(7)*

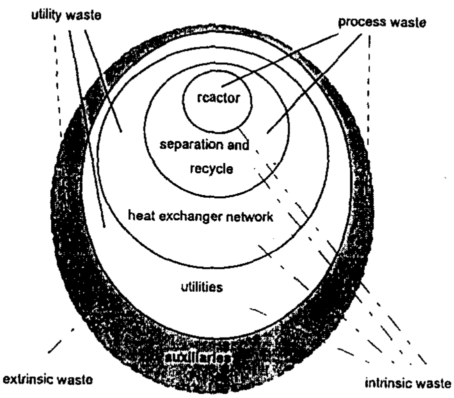


Figure 2. Extended onion diagram

This hierarchical decision procedure described by Douglas *(4)* provides a simple way of identifying potential pollution problems early in the development stages of a design. The procedure also can be used to decompose existing designs, and then process alternatives that eliminate existing pollution sources can be identified. Douglas *(2)* lists several waste minimisation problems according to his procedure and identifies solution alternatives.

Rossiter *et al. (5)* have applied this procedure for a fluid catalytic cracking unit. Fonyo *et al. (6)* have developed the strategy of Douglas for retrofitting problems. In their systematic procedure first they define and track the wastes, afterwards they collect data for waste streams, produce waste minimisation alternatives, and finally technical and economical alternatives are evaluated.

The other major hierarchical approach has been proposed by Linnhoff *et al. (7)*. They have used the *onion diagram* to emphasise the sequential or hierarchical nature of process design, starting with the reactor and following with subsequent layers of separation system, a heat exchanger network, and a utility system (Figure 1).

Smith and Petela *(3)* have developed their systematic procedure based on the onion diagram for waste minimisation in the process industries. They have identified two classes of waste from chemical processes and located their origins to the layers of the onion diagram. The two inner layers of the onion produce *process waste* that is defined as waste by-products and purge streams. The outer two layers of the onion produce *utility waste*. Utility waste is flue gas and ash from fuel combustion, waste from boiler feedwater treatment, cooling water, etc. The utility waste is associated with the energy consumption and it is also a target to be minimised for a given process *(8)*. The systematic procedure proposed by Smith and Petela *(3)* follows the way of process synthesis according to the onion diagram considering waste minimisation.

Berglund and Lawson *(9)* have classified waste streams as *intrinsic* wastes that are inherent in the fundamental process configuration and *extrinsic* wastes that are associated with the auxiliary aspects of the operation. Extrinsic wastes may occur as a result of unit upsets, selection of auxiliary equipment, fugitive leaks, storing problems, process shutdown, sample collection and handling, etc. The onion diagram does not include the auxiliaries because they have not been involved in the hierarchical process design. However, when waste minimisation is considered we have to extend the onion diagram with a fifth fictive layer *(10)* which represents the auxiliaries (Figure 2).

In Table 2 possible sources of process and utility wastes and solution alternatives are listed according to the extended onion diagram based on the work of Smith and Petela *(3)* and Mizsey *(10)*. It is to be noted that the decisions made for waste minimisation on the subsequent layers are not independent of each other and the interactions and interconnections are to be considered according to the basic theory of hierarchical process design.

## Waste minimisation on the company level

The systematic techniques developed and used for process improvements are very powerful tools for waste minimisation on the process or plant level. Current technologies are being used to develop processes for effluent reduction. However, these operations will also reach their limits and a third generation of waste minimisation is inevitable. New design methods for process synthesis will be developed to further minimise the process waste emission by maximising mass efficiency. These methods are to be able to include not only one chemical process or plant but they can investigate more processes or plants trying to eliminate the global emissions of the plants included in a chemical company.

Table 2

*Possible sources of process and utility waste and solution alternatives according to the extended onion diagram*

| LAYER | PROCESS WASTE | |
|---|---|---|
| | *possible source* | *solution alternative* |
| *Reactor* | difficult to separate and recycle unreacted feed material | increase conversion |
| | primary reaction produces waste<br><br>secondary reaction produces waste<br><br>impurities in the feed material become waste or react to produce waste<br><br>degraded catalyst | Consider:<br>• different reaction path<br>• rector type<br>• reactor temp., pressure<br>• excess reactant<br>• product removal during<br>• reaction<br>• different feed material (consider separation)<br>• different catalyst |
| | poor control and operation, non-optimal conditions | improve unit operation and control |
| *Separation and recycle* | feed impurities | purify feed (consider reaction operation) |
| | extraneous material for separation | eliminate extraneous material by process modifications |
| | unrecycled waste streams | carry out additional separation of waste streams |
| | waste produced in reversible reaction | separate and recycle waste |
| *Auxiliaries* | start up and shutdown losses | minimise the number of shutdown by designing for high availability, plant maintenance, and flexible operation |
| | storing | • improve storing facilities,<br>• improve inventory management,<br>• better housekeeping |
| | equipment cleaning | • use reliable equipment<br>• design for a small in-process inventory |
| | fugitive emissions | • use reliable equipment<br>• improve maintenance |
| | sampling | closed-loop sampling |

| LAYER | UTILITY WASTE | |
|---|---|---|
| | *possible source* | *solution alternatives* |
| *Heat exchanger network, utilities* | direct emissions from the plant and its utility system (on-site emissions from utility system and off-site emissions from power station) | • increase the energy efficiency of the process (pinch technology, Linnhoff *et al. (7)*)<br>• switch fuel<br>• desulphurise fuel and flue gas<br>• select low $NO_x$ burners<br>• recirculate flue gas<br>• chemical reduction |

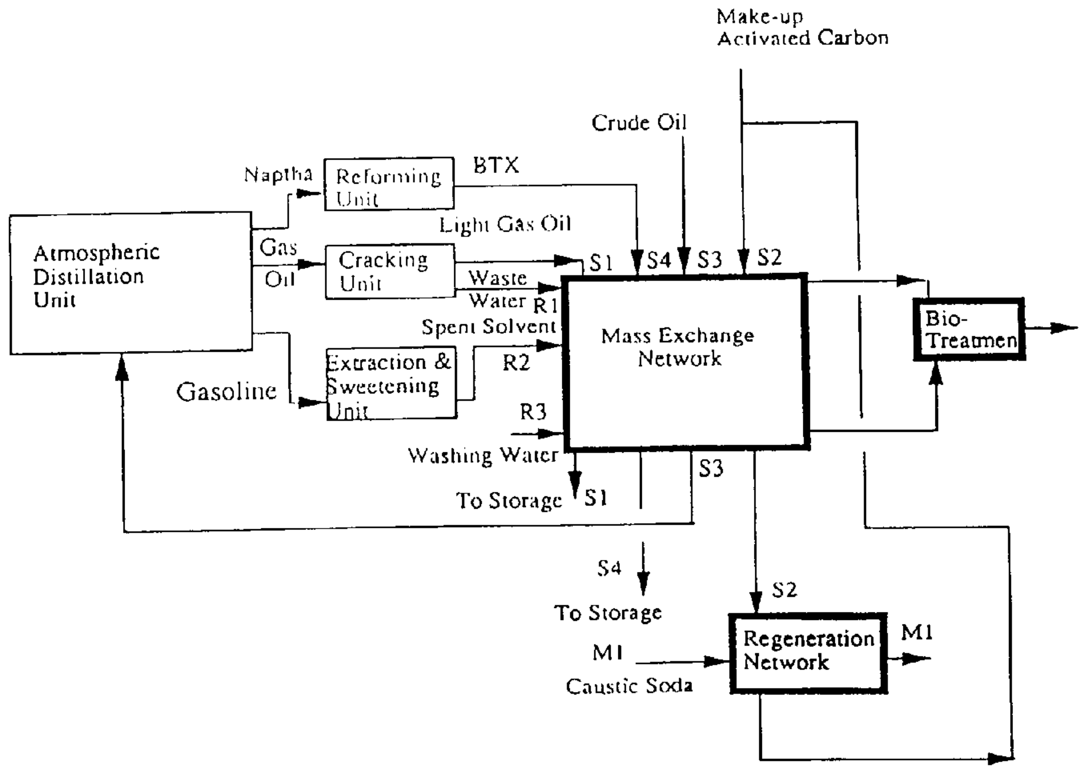


Figure 3. Phenol recovery problem in a refinery *(12)*

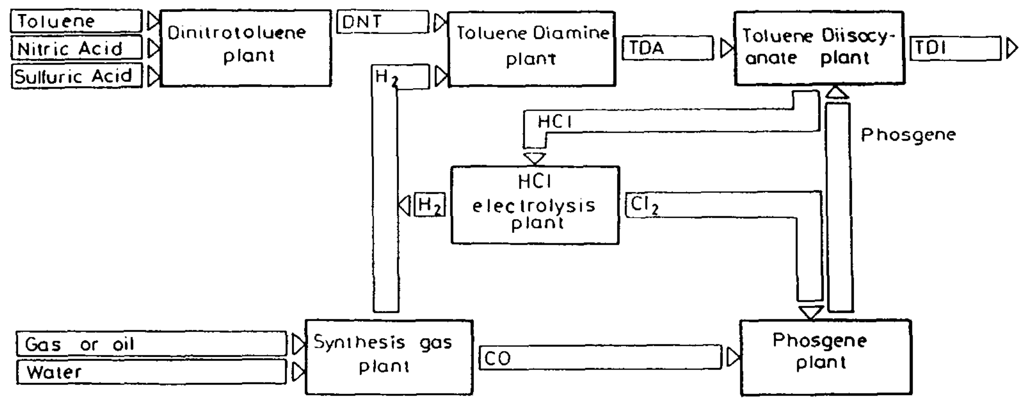


Figure 4. Toluene Diisocyanate production *(13)*

It is easier to extend the investigation in the case of minimising the utility emissions. Several design methods have been developed to synthesise heat exchanger networks (HEN's) where the energy lost is a minimum, e.g. pinch technology *(7)*. The pinch technology is able to handle more plants at the same time.

The problem of process waste seems to be more complicated although the design problem is somewhat analogous to the design of energy efficient processes. El-Halwagi and Manousiouthakis *(11)* have developed the concept of mass exchange networks (MEN's) and proposed a systematic procedure for the synthesis of MEN's.

A mass exchange network consists of separators and mass transfer units that achieves, in a cost effective manner, minimal emission of hazardous waste. The synthesis problem can be formulated as: given a set of pollutant rich streams and a set of pollutant lean streams, synthesise a MEN, that is a set of separators and transfer units, that can transfer the pollutant species from the rich streams to the lean streams at minimum venture cost. A key feature of this approach is that it combines thermodynamic and driving force constraints into the optimisation. Cohen and Allen *(12)* have implemented this approach in a refinery. In that particular refinery one of the waste components of interest in waste waters is phenol. In other streams of other plants in the refinery phenol can be a valuable additive. The aim of the MEN synthesis problem is to identify the optimal process configuration for transferring phenol between these streams. A simplified version of the mass exchange problem is shown in Figure 3. By using linear programming and mixed-integer non-linear programming formulation the optimal mass exchange network is obtained that recovers 96.7% of the phenol present in the rich streams.

The aim of third generation modification is to design such processing that only products leave the global system. Within the frame of a company we integrate plants if certain component(s) of the waste streams leaving one of the plants can be utilised in another plant as raw material. This is the so called closed-cycle processing that is an effective method for waste elimination incentives and it is practically an effort to copy the processes taking place in the nature, which are all closed-cycle processes.

Kiwitt *(13)* represents this closed-cycle processing with the example of the Toluene Diisocyanate production (Figure 4). Other case studies are presented in Reference *(14)*.

# A systematic two level procedure for process waste elimination

The waste minimisation incentives at the chemical plants should be co-ordinated on a higher level, on the company level. A two level systematic procedure might be used according to this two level problem. The systematic procedure (Figure 5) investigates the plants of the company. During the operation of the plants good housekeeping practices, inventory control, and minor changes in operation practices should be considered. Afterwards, the systematic two level procedure identifies process waste and the raw material requirements of every plant in the company. It is necessary to investigate before making some further major improvements on the plant level for waste minimisation whether the waste streams and the raw material requirements can be matched. If the sources and sinks cannot be matched it is to be investigated whether some modifications could still help to realise a match of a waste stream and a raw material requirement, e.g. Reference *(15)*.

*The main goal is to utilise the waste of a plant in another plant that is to design closed-cycle processing.* MEN synthesis can be completed if necessary. If MEN is not acceptable, the investigation is to be continued on the plant level.

If the waste minimisation or elimination cannot be completed by closed-cycle processing, the waste minimisation activities are to be continued on the plant level again considering major process improvements. These activities can be carried out according to one of the systematic procedures developed for waste minimisation on the plant/process level. If the waste cannot be eliminated it can be investigated again whether further modification of the sink and/or source plants could help or not. This investigation is necessary because the major process improvements carried out on the plant level can change the waste and the raw material requirements of the plants.

Waste that cannot be eliminated should be incinerated, treated, or disposed.

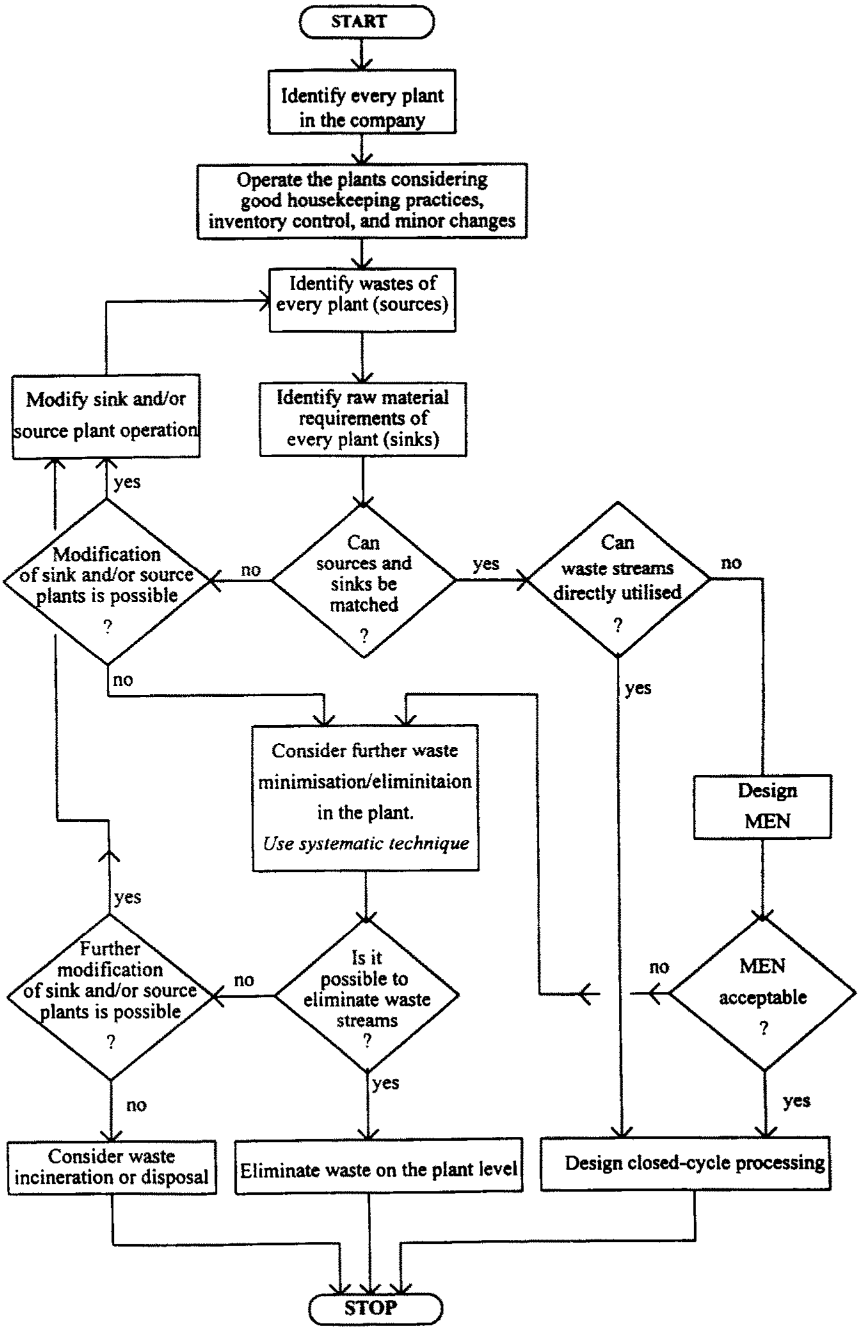


Figure 5. Systematic two level procedure for process waste elimination

## In summary

If "cleaner" processes are to be designed it is not enough to concentrate on the waste minimisation on the plant level. The decisions should be co-ordinated on a higher level, on the company level, considering the possible interactions among the different plants. Closed-cycle processing and minimal global emission can be designed with the use of the proposed systematic two level procedure for waste elimination.

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