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# CONCEPTS FOR THE REDUCTION OF INDUSTRIAL WASTES

This document was prepared by Messrs. Georg Goosmann and Hans Sutter, consultants to the Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ). The views expressed in this work are the sole responsibility of the authors and do not necessarily coincide with those of the Organization. Document not subjected to editorial revision.

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## INTRODUCTION

Over the last few years the basic concepts of industrial solid waste management have changed substantially, not only in its underlying philosophy, but in its technical and administrative aspects as well.

In the Federal Republic of Germany, the first waste management legislation was effected in 1972, which at the time dealt with organizational and planning requirements for the collection, treatment and final disposal of wastes and the necessary supervision. With some negligible exceptions, these regulative measures were limited to what takes place after "the end of the pipe".

Indicative of the intended progress towards source reduction, the Waste Disposal Act became the Waste Avoidance and Management Act coincidental with its 4th amendment in 1986. The basic tenets of this updated legislation specified that waste generation must be avoided as far as technically possible and economically acceptable and that waste must be recycled unless this is economically not feasable. Waste that can neither be avoided nor used with reasonable costs must be disposed of in an environmentally sound way. Therefore, one main objective of the new waste legislation is to give low-waste technologies priority over customary waste disposal.

In the context of this paper, the term "low-waste technology" refers to industrial waste management and reduction and recycling intended to reduce the amount of waste requiring waste disposal capacity. It includes in-plant measures (source reduction), as well as environmentally sound reuse in external plants.

## END-OF-PIPE TECHNOLOGIES

The main reason for this new philosophy of eliminating hazardous waste at its source and using low-waste technologies lies in the shortcomings of the end-of-the-pipe technology concept to fight industrial pollution (Figure 1). The figure depicts an industrial process and the necessary end-of-pipe equipment for air pollution control, waste water treatment and waste disposal (Sutter, 1988b). Industrial production and environmental pollution caused by industrial processes have much to do with material flows. According to the mass balance, the input materials are transformed into products and residues. The products - the main objective of production - are marketed, whereas the redsidues enter the environment through three different pathways: the air, water or hazardous waste path. In the air pollution control system, the contaminants are removed from the waste air stream and transformed into waste water or solid waste. Only a residual stream that meets the legally established standards is emitted into the environment. In principle, the same happens in the waste water treatment system: the contaminants are removed from the waste water and transformed into a solid state and disposed of as waste.

Three waste streams enter the waste disposal system, one of which originates directly from the production process. These wastes are unwanted byproducts and therefore, often neglected in the design of the process, especially when there is the possibility of getting rid of them by emitting them into the environment. The other two waste streams stem from the air pollution control system and the waste water treatment system.

The waste disposal system itself is end-of-pipe technology and consists mainly of two parts (Sutter, 1988a)(Figure 2):

- the pre-treatment system
- the final disposal in specially designed chemical landfills.

In the pre-treatment system, the wastes are converted from hazardous into less or non-hazardous materials, at the same time reducing the bulk of the waste and thus the landfill volume required. The methods used to accomplish these objectives can be classified into three major treatments: physical, chemical and thermal. A variety of technologies can be found in each of these groups. The most important pre-treatment method is incineration. The hazardous waste treatment system itself produces waste that must finally be disposed of on land. In addition, waste water and gaseous emissions result from these operations.

In the Federal Republic of Germany, the land disposal of many untreated hazardous wastes must be phased out according to the 1990 requirements of the "Technical Instructions for Hazardous Waste", an administrative ordinance implementing the new waste act. These regulations were to produce nationally applicable technical standards for the treatment and disposal of waste based on the latest advances in technology. However, relying solely on treatment and the establishment of strict controls on land disposal cannot fully solve hazardous waste problems. It is essential that the generation of hazardous waste be minimized by using low-waste technologies.

## LOW-WASTE TECHNOLOGIES

### Concepts

From an environmental point of view, a production system can be roughly explained as shown in Figure 3. The input materials are transformed into products and residues. It is important to differentiate raw materials from auxiliary materials because they affect the development of low-waste technologies differently (Sutter, 1988b).

The raw materials consist of different components, among which the valuable part that goes into the product can be found. This might be, for instance, copper in a copper-containing ore. In the production of vinyl chloride, it is chlorine and ethylene. Beside these valuable parts, there are unwanted components like rocks in copper ores.

As Figure 3 shows, only the valuable parts of the raw material end up in the product, whereas the other components create residue problems. The same happens with the so-called auxiliary materials. Their function is to enable production; they are not intended to be present in the product. Hence, all the auxiliary material inputs result in residues. Examples of auxiliary materials are acids, chlorinated solvents, foundry sands or salts in smelting processes.

In traditional engineering, normally, only the reaction between the valuable part of the raw materials and its use in the product is of interest. The other components and the auxiliary materials are often neglected and not considered in material balances since they are released into the environment. However, from an environmental point of view, these material flows are of paramount concern as they cause many of the industrial pollution problems.

Figure 3 also suggests the possible economic benefits of low-waste technologies. Processes with a high waste production consume a greater amount of input materials. The total amount of auxiliary materials ends up in the waste stream. If the process is not efficiently run, a certain amount of the valuable part of the raw materials - which can be very high - is transformed into waste and not into a product. Improving the efficiency of input material use means nothing else than minimizing waste. In other words, waste minimization means less material input and less cost. In this respect, ecology and economy go hand in hand.

Developing low-waste technologies answers the question: What can be done with the residues as an alternative to their disposal (Sutter, 1988b)? In the concepts shown in Figure 4, case "a" is a diagram representing an open production system, where all the residues are emitted directly into the environment. In case "b", the residues are reused as secondary raw materials in other production processes. If the waste stream consists only of auxiliary materials, then in principle, case "c", a closed-loop cycle, can be built up to avoid all waste. As Figure 3 indicates, substitution of raw materials or auxiliary materials is the third option to develop low-waste technologies.

**Open System**. In an open system, all the input materials are transformed into products and residues, which are emitted directly into the environment. The relationship between the input materials that end up in products and those which are left in the residues is dependent upon the particular process and can differ greatly from branch to branch. In chromium galvanizing, only 25 percent of the input material is used for the product, while 75 percent is transformed into residues that enter the environment via the waste water path or as galvanic sludge. A similar situation occurs with industrial spray-painting, where 25 percent of the input paint stays on the product and 75 percent is emitted into the environment by the air or solid waste path. In the Federal Republic of Germany, about 350,000 tons of non-halogenated solvents are emitted and 250,000 tons of paint sludges have to be disposed of, which together have a raw material value of about one billion Marks per year.

There are many other examples available of the poor usage of raw materials and high waste production. Clearly, these processes are good candidates for developing low-waste technologies because improving the waste situation results in better material usage and economic advantages over traditional processes.

**Reuse**. The open system can be partially closed by reusing the residues as raw materials in other production processes. This depends on the composition of the residual stream and if it can be partially recycled internally (Figure 4) or if it must be reprocessed completely to produce a new product or a new intermediate product.

**Closed-Loop System.** Principally, in cases where the waste stream consists only of auxiliary materials (and these cases are of great importance in the hazardous waste field), a closed-loop cycle can be created to avoid the production of waste entirely.

**Substitution.** Another approach in developing low-waste technoligies lies in the substitution of those substances (raw or auxiliary materials) that create the waste problem. Normally, this approach requires a completely new process design. An example is the subsitution of chlorinated solvents in metal cleaning by water-based systems.

## EXAMPLES

Due to the increasing importance of low-waste technologies for the solution of hazardous waste problems, research and development projects for the avoidance and utilization of hazardous waste have begun in many different industries in recent years. The results demonstrate that new solutions can be found if the streams that are needed in the product and the streams that pollute the environment are given the same priority.

### Salt Slags

There are two ways of producing aluminum - by primary and secondary production. While primary aluminum is made from the ore directly, secondary aluminum is recovered from wastes and scrap. Usually, wastes and scrap are melted under a salt cover consisting of NaCl and KCl (Figure 5). The salt cover serves to absorb impurities adhering to the material used. On an average, 0.2 ton of salt are needed per ton of scrap input. The salt is an auxiliary material and leaves the melting process with the waste, termed salt slags. The salt slags contain about 7 percent aluminum, 60 percent salt and the impurities brought into the process by the scrap input. On an average 0.4 ton salt slags are created by melting one ton of input material.

Until recently, the total amount of salt slags, roughly 200,000 tons per year, were disposed of in landfills in the Federal Republic of Germany, causing severe environmental problems. In order to close this open system, a method for converting the salt slag into valuable materials was developed (Umweltbundesamt, 1983). A closed-loop system can be built for the salt and a high rate of aluminum recovery is guaranteed (Figure 5). Reprocessing the salt slags helps both to avoid severe damage to the environment and to recover raw materials. Recently, a plant with a capacity of 60,000 tons of salt slag per year started work in the Federal Republic of Germany.

## Chemical Industry

**Chlororganic Chemical Industry.** A major hazardous waste problem of the organic chemical industry is the chlorinated hydrocarbon residues generated, for example, in the production of vinyl chloride, propylene oxide, per- and tri-chlorethylene, chlorinated benzene and certain pesticides. In 1981, 2.5 million tons of chlororganic products were manufactured in Germany, creating about 185,000 tons of chlorinated hydrocarbon residues (Schulze and Weiser, 1985). Of this amount, 45,000 tons were disposed of by incineration at sea, whereas the major portion of 140,000 tons was reused as raw materials through the application of low-waste technologies. For example, 60,000 tons were used as input for perchlorination processes and 26,000 tons for the production of hydrogen chloride. Since 1981, the amount incinerated at sea has been further reduced, mainly by burning to obtain hydrochloric acid that can be recycled in the process or directly introduced as flue gas into chemical reactors.

Avoidance in the chlororganic chemical industry may also be promoted by process substitution. The substitution of chlorine-based processes with non-chlorine-based processes is primarily of importance in the production of propylene oxide in which the chlorohydrine procedure has been replaced by the isocyanide procedure.

Another example is the substitution of the amalgam process by the membrane process to produce chlorine, a change that results in avoiding the mercury-contaminated brine sludges.

**Sulfuric Acid Wastes.** Numerous waste acids arise from the use of sulfuric acid in the organic chemical industry, in oil refineries and in the production of pesticides. Often, wastes are heavily contaminated by organic substances. Disposing of them in landfills may cause severe problems. A broad spectrum of waste acid sludges and tars containing sulfur are treatable in a recently developed procedure (Umweltbundesamt, 1985). The procedure involves producing $SO_2$ of sufficient purity to be used in the manufacturing of additional products

(Figure 6). Both desirable and undesirable reactions take place concurrently during thermal splitting. The desired reaction is the complete combustion of organic compounds, this requiring high temperatures and an excess of oxygen. The undesirable reactions arising under these conditions result in the formation of nitric oxide and sulfur trioxide. Separating the overall reaction into several stages enables not only the organic compounds to be completely oxidized, but also the formation of nitrogen oxides and sulfur trioxide to be largely suppressed.

Another problem are the wastes from the titanium dioxide industry. In the Federal Republic of Germany, this industry creates about 1.3 million tons of waste per year (diluted acid) contaminated with heavy metals, which are presently dumped in the North Sea. This amount of waste cannot be disposed of on land in the traditional way, which is to neutralize it and then dispose of it in landfills. For that reason, all concepts for the solution of the problem have to proceed from avoidance or reutilization. Here the aim is always the recycling of the diluted waste acid under energetically advantageous conditions. Bearing this in mind, research and development projects for the solution of the waste problem of the titanium dioxide industry have been carried out and have provided the basis for a national program towards the step-wise reduction and termination of the dumping of wastes for all German $TiO_2$ production plants. The dumping at sea was stopped at the end of 1989. That means that from this time on about 1.3 million tons of diluted acid per year are being utilized and handled in a closed-loop titanium dioxide production system.

## Metal Finishing Industry

Another important industry that contributes much to hazardous waste problems is the metal finishing industry. This industry uses a large number of industrial processes for machining and for the surface treatment of metals and other materials. Figure 7 shows typical operations in machine shops where metals or other materials like metal-plated plastics are formed and surface treatment is accomplished. Operations in the machine shops include machining to form or cut metal parts, cleaning and degreasing of the parts and the final steps of pickling and electroplating. In some shops just machining or just electroplating is carried out. In other shops all of these operations are going on to produce the finished metal parts.

The processes shown in Figure 7 involve the use of a wide range of chemicals that may subsequently appear in liquid, sludge or solid waste form. The main hazardous waste streams are shown. These are spent solvents and lubricating oils in emulsion form, spent chlorinated solvents, spent acids and lost plating solutions in the form of spent baths and drag-out-rinse containing toxic heavy metals like cadmium. These wastes cause severe environmental problems. Investigations in Germany have shown that in the vicinity of many machine shops the ground water contained such a high concentration of chlorinated hydrocarbons that wells had to be closed - this because the spent solvents had often been dumped on-site. There are other examples where the improper handling of spent plating solutions has resulted in severe chromium and cadmium contaminations of the ground water.

## Electroplating

In the last decade, a large variety of closed-loop processes and recovery procedures for clean technology in electroplating and metal finishing have been developed in Germany. As a result, the consumption of chemicals has been effectively reduced. Simultaneously, smaller volumes of process solutions are lost, resulting in lower impact on the environment from waste water and sludges. The objective of further research work for water and waste management is focused on a reduction of wastes by low-effluent and effluent-free production methods, mainly attainable by operating closed-loop processes (Boehm, 1986).

## Spray painting

Another low-waste technology in metal finishing should also be mentioned in this short review: reuse of overspray from spray painting chambers. With spray painting, some of the paint is certain to be lost and not sprayed on the object being painted. The amount of such "overspray" is about 50 percent, leading to paint sludges. Economic conditions for the implementation of reduction measures are favorable and there are different ways to reuse paint sludges. In one method, a recovery disk is set in the spray booth directly behind the work piece to collect part of the overspray and to recycle the paints immediately. A stripper removes the paint, almost in its original condition, from the rotating disk. In practice, up to 80 percent of the overspray can be recovered, reprocessed by addition of solvents, filtered and returned into storage tanks for reapplication (Umweltbundesamt, 1982).

In another method, paint sludges are processed to recover different components like resins and pigments. A third method is the use of the paint sludge to form parts that can be used, for instance, in the auto industry. These three ways are presently being investigated and plans to build recovery plants on a large scale exist in the Federal Republic of Germany.

**REDUCTION POTENTIAL**

The new developments in low-waste technology have already led to reductions in hazardous waste generation and will continue to do so. An estimate of the future potential in waste reduction by applying low-waste technologies is given in Table 1. The estimate is based on the amounts of hazardous waste disposed of in the year 1983 by the Federal Republic of Germany. It is an evaluation of the so-called trip-tickets that are used to control the transportation and disposal of toxic hazardous wastes (Sutter, 1988b). A partial evaluation of 1987 data confirmed, more or less, the findings derived from the 1983 data basis. It seems, therefore, admissible to exemplify the typical trends still using the old data basis.

In 1983, 4.9 million tons of toxic hazardous waste were disposed of (Table 1). About 40 percent of these were sulfur-containing wastes consisting of 1.3 million tons of diluted sulfuric acids (mainly from the titanium-dioxide industry) and about 800,000 tons of gypsum contaminated with organic components from many different chemical processes. The phosphor gypsum is not included in this sum. The sulfur-containing wastes include other wastes such as acid tars.

| | Waste Arisings 1983 (Million Tons) | Potential for Reduction by end of 1999 (%) |
|---|---|---|
| Sulphur Containing Wastes (acids, gypsum) | 2.2 | 80 |
| Oil-containing wastes | 0.5 | 40-50 |
| Paint wastes (residues from industrial painting) | 0.3 | 60-70 |
| Organic Solvents | 0.3 | 60-70 |
| Electro-Plating Residues | 0.2 | 60-70 |
| Salt Slags from Secondary Aluminum Smelting | 0.2 | 100 |
| Other Wastes | 1.2 | low |
| TOTAL | 4.9 | 50-60 |

**Table 1: Reduction Potential Estimates**

Waste emulsions contribute about half a million tons to the total amount of hazardous wastes. Other important waste categories are paint sludges and solvents, halogenated and nonhalogenated, from many different industrial sources, which make up 300,000 tons each.

Galvanic sludges of different types and salt slags from the secondary aluminum melting industry accounted for about 200,000 tons each in 1983. The remainder of the 1.2 million tons falls into many different waste categories for which relatively low reduction potentials have thus far been estimated to exist.

The main sources for the creation of toxic hazardous waste are the chemical industry and the use of chemical products in different industrial branches, as for example, the use of acids, solvents or paints in the metal finishing and coating industry.

Under present technical and economic conditions, a total reduction of 50 to 60 percent within the next ten years or so seems to be possible. With the use of solvents and in some industries such as the galvanizing industry and in spray painting, a reduction of 60 to 70 percent can be reached. Mainly, by recycling the diluted waste acids, it is possible to reduce the sulfur-containing waste category by about 80 percent. A 100 percent reduction is possible in the area of salt slags generated by the secondary aluminum industry.

Nontheless, as shown in Table 1, a one hundred percent reduction or a one hundred percent recycling is seldom possible; a certain amount of hazardous waste still remains to be treated and disposed of. It is important to do this in an environmentally safe way in order to avoid the creation of new problems for the future.

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# ANNEXES

Figure 1. End-of-Pipe Technology Concept

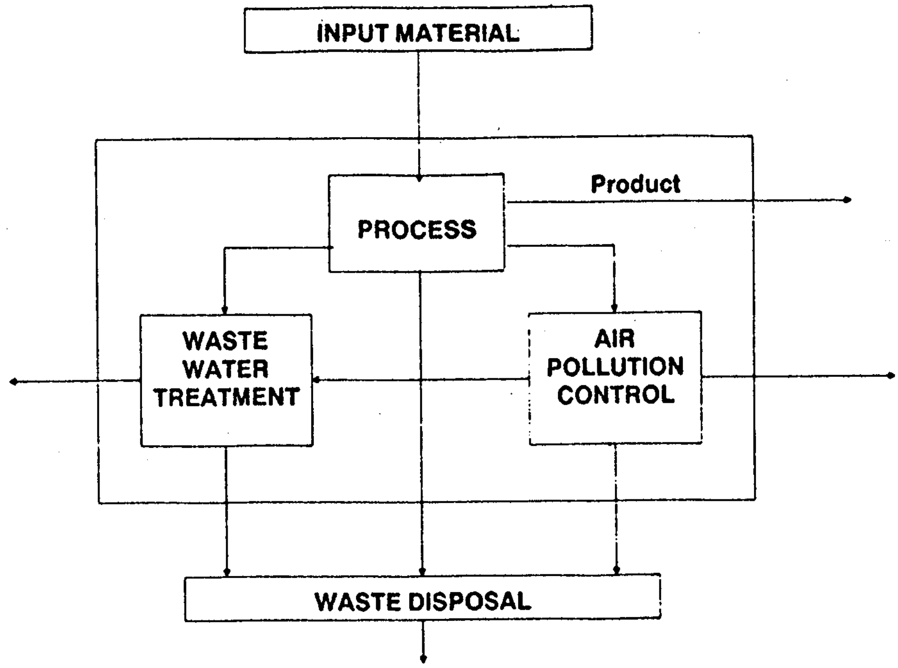


Figure 2. Hazardous Waste Treatment and Disposal System

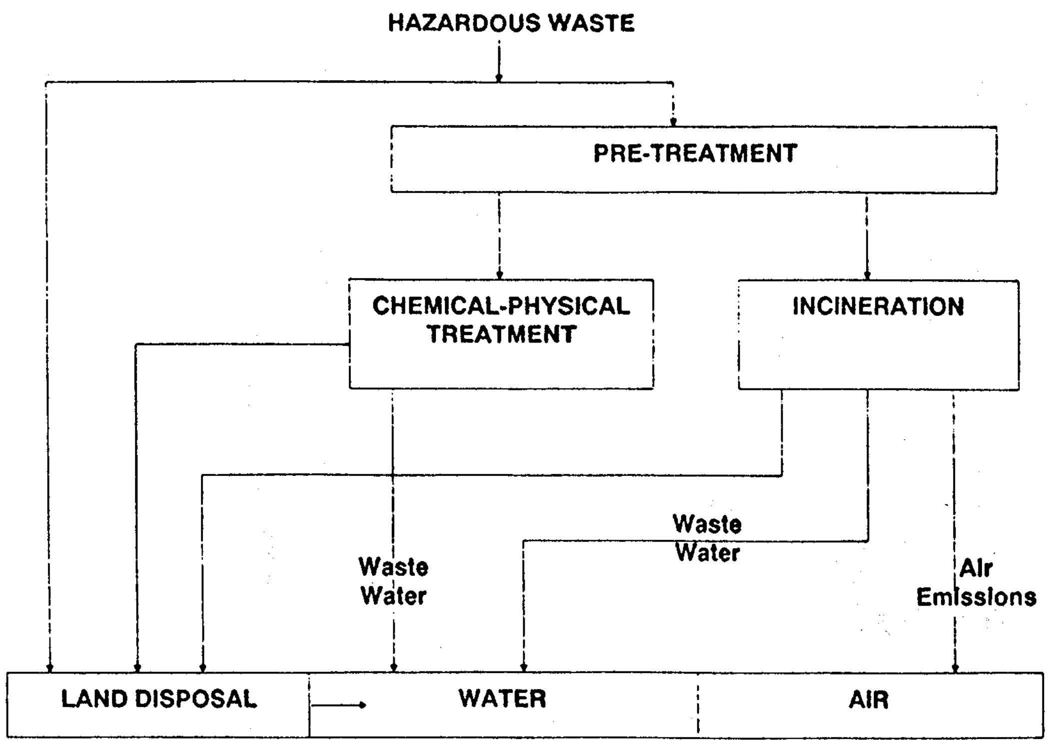

Figure 3. Material Flows

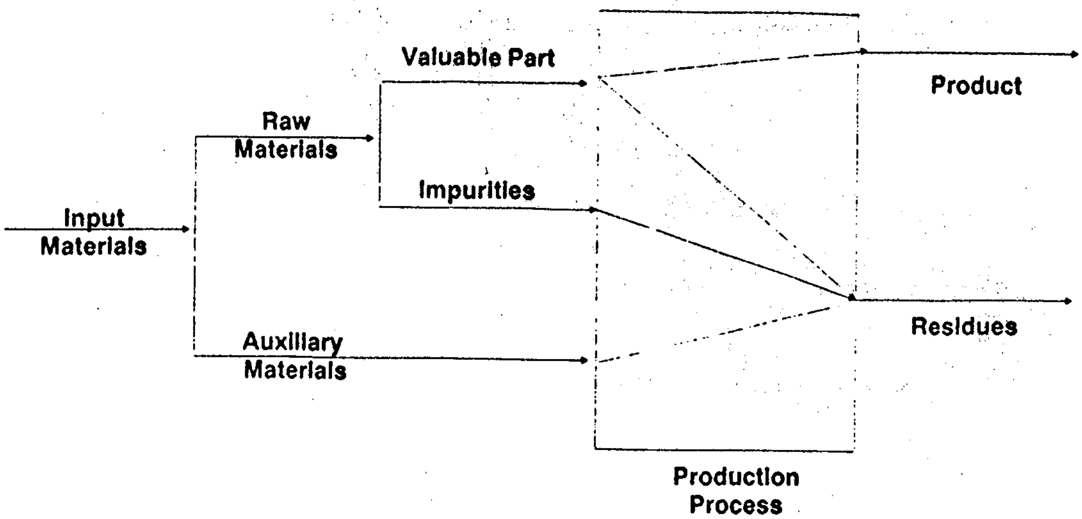


Figure 4. Concepts of Low-Waste Technologies

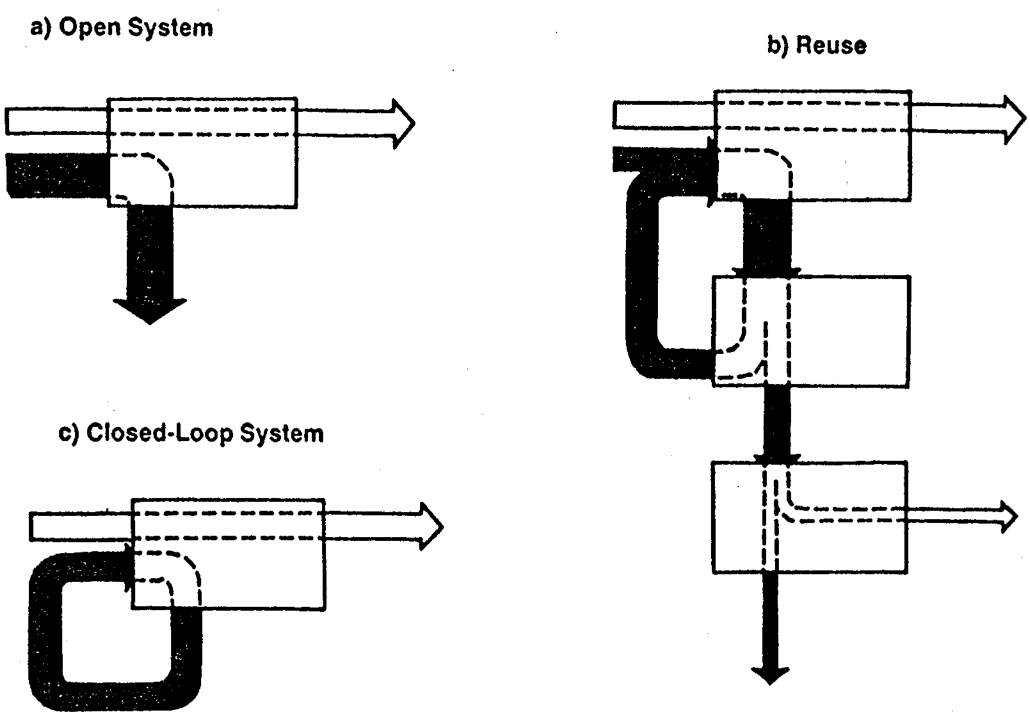

Figure 5. Reprocessing of Salt Slags

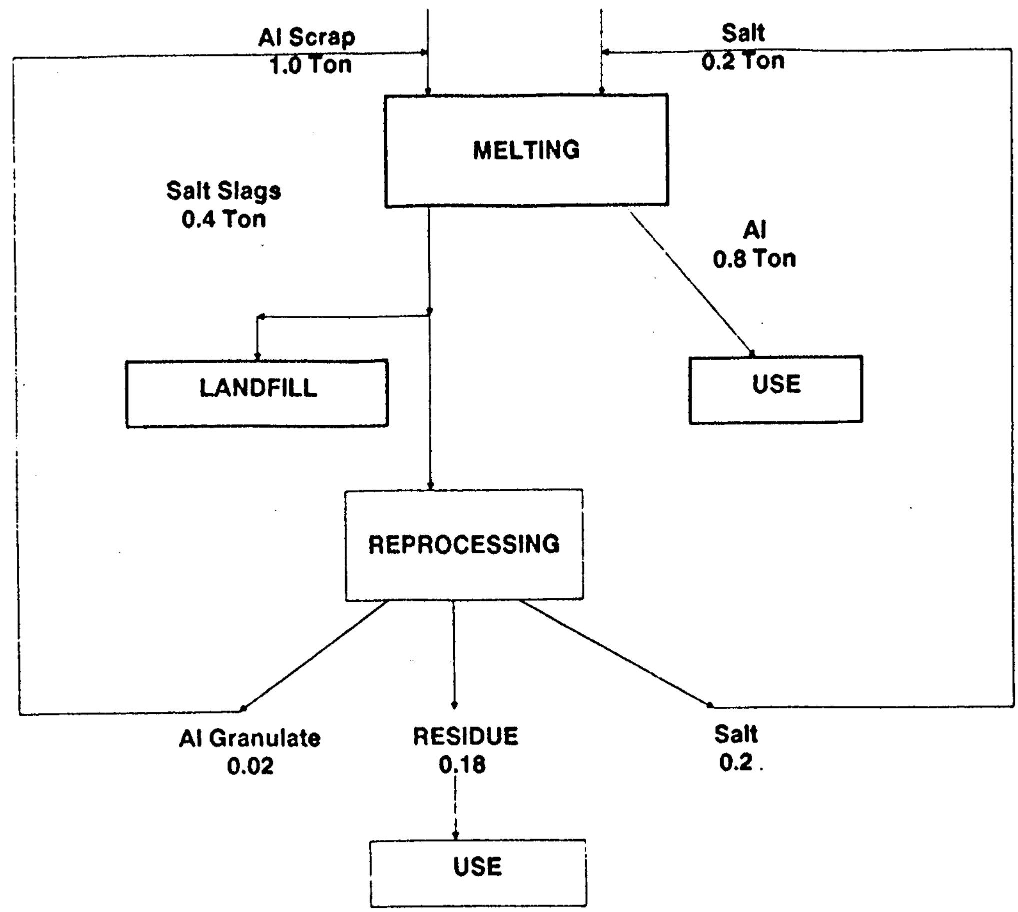


Figure 6. Scheme of the Installation to Utilize Sulfur-Contamining Waste