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Process engineering for pollution control and waste minimisation in non-ferrous metallurgical industries

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ABSTRACT

The importance of industrial ecology in the materials cycle has been stressed. The different approaches to process design have been outlined and typical applications to non-ferrous metallurgy have been highlighted. The challenges and opportunities for pollution control and waste minimisation in the non-ferrous metallurgical industries with reference to gaseous emissions, liquid effluents and solid wastes have been examined.

Keywords : Process engineering, Pollution control, Pinch technology, Solid wastes, Liquid effluents.

INTRODUCTION

Since the eighties, there has been a major upheaval for the primary non-ferrous metallurgical industries. The twin pressures of competition and environmental constraints have forced the industry to rethink many fundamental approaches to process metallurgy. Of late, there has been a shift in paradigm from a "cradle to grave" approach to a "cradle to reincarnation" concept, utilising an holistic integrated systems approach. The concept of "industrial ecology" is the need of the hour. This may be defined as a new approach to the industrial design of products and processes and the implementation of sustainable manufacturing strategies. It is a concept in which an industrial system is viewed, not in isolation from its surrounding systems, but in concert with them. Industrial ecology seeks to optimize the total material cycle from virgin materials to finished materials, to components, to products, to waste products and to ultimate disposal [1]. This is schematically depicted [2] in Fig. 1. Such a concept assumes greater significance in the non-ferrous metallurgical industries, where the metal values are becoming increasingly leaner in grade, resulting in large tonnages of ore to be processed, inevitably leading to huge accumulations of solid wastes. For ex-

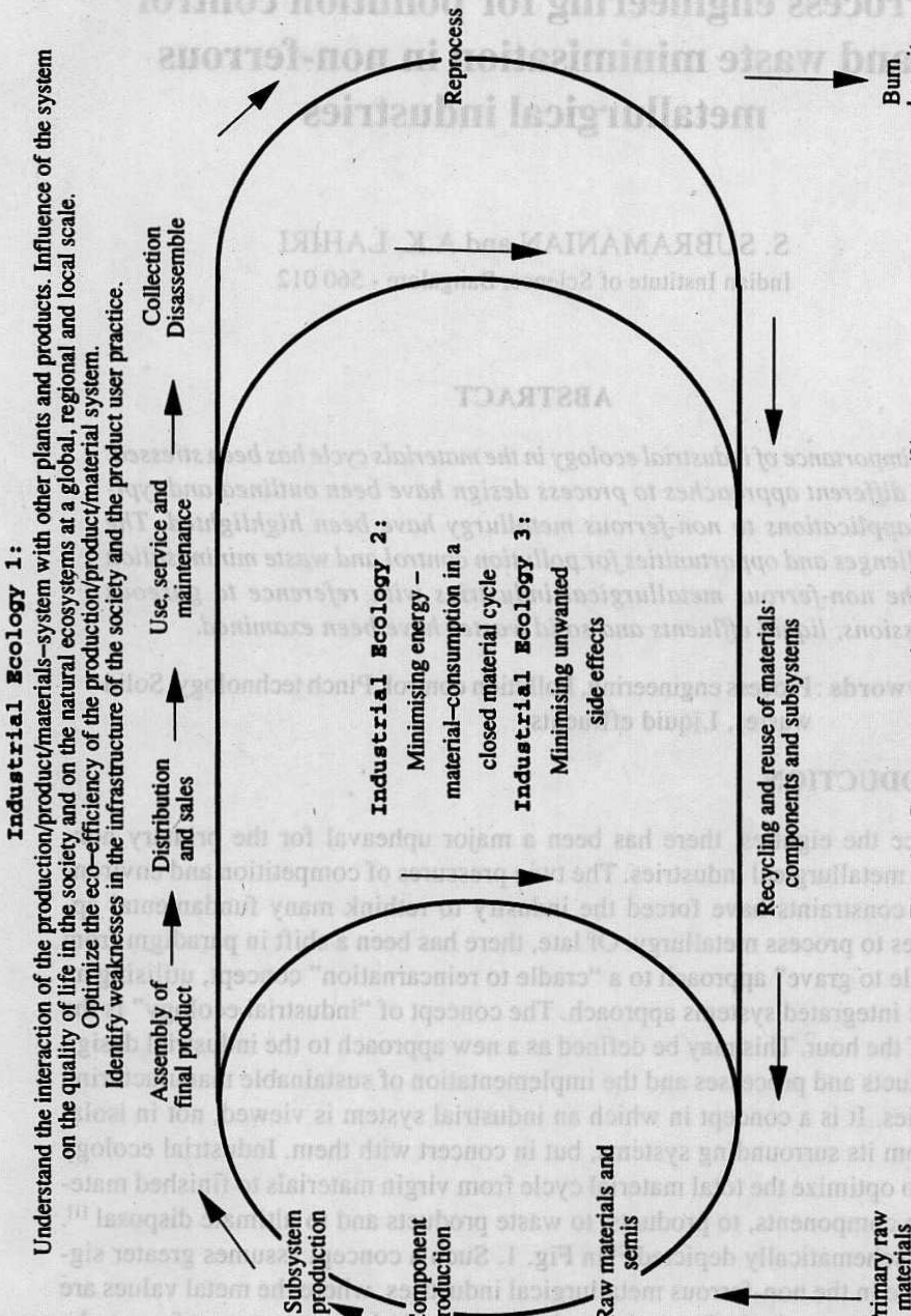

Fig. 1 : Concept of industrial ecology [2].

ample, the average tenor of gold currently processed in India is about 4 ppm, while for copper it is about 1%, between 5-10% for zinc and about 2-5% for lead. In this context, recycling of non-ferrous metal occupies a central position apart from re-utilisation of existing waste dumps and stockpiles. It has been reported [3] that by-product materials can be effectively treated by current extractive metallurgical processes in an environmentally benign manner and waste materials may be considered as viable recyclable materials. Similarly, several methods are available for recycling precious metals such as gold, silver and platinum. The rapid growth of the aluminium recycling industry is a matter of gratification. The possibilities of optimising metallurgical processes for waste reduction and application requirements for the reuse of waste products including slags have been highlighted by Bjorkman, et al. [4].

Non-ferrous metallurgical industries form a wide range of industries and processes, from primary metal producing to metal finishing and plating. Besides, the secondary metal producing industries are becoming a very important sector both for metal production as well as utilization of hazardous wastes. Obviously, the pollution control and waste minimisation techniques for each of these industries are different. The present article, therefore, does not aim at reviewing the techniques most suitable or used by the industries but aims at discussing the process engineering approach to solve the problem.

It is now well recognised that end of pipe solution is not ideal for pollution control. The pollution control and minimisation of waste should form an integral part of process design. In other words, the production process or detailed flowsheet should be so designed that the levels of pollutants in all the discharged streams are well within the tolerable limits. The availability of large number of alternatives for the same desired end product makes the choice of process design complex. The methods for finding an optimal solution for the problem has already become a subject of investigation in its own right.

DESIGN METHOD FOR POLLUTION PREVENTION

Over the years, a number of different systematic approaches to process design have been developed. These methodologies do not, in general, attempt to invent any new types of equipment or unit operations but help to ascertain the proper selection and integration of existing technologies so that the desired result with optimum capital and energy costs is achieved. Spriggs [5] categorized the design methods into (i) Hierarchical review and other methods of structured thinking (ii) Mathematical approaches and (iii) Thermodynamic approaches. The methods of first type are also known as knowledge based approaches and the thermodynamic approach is mostly referred to as pinch analysis.

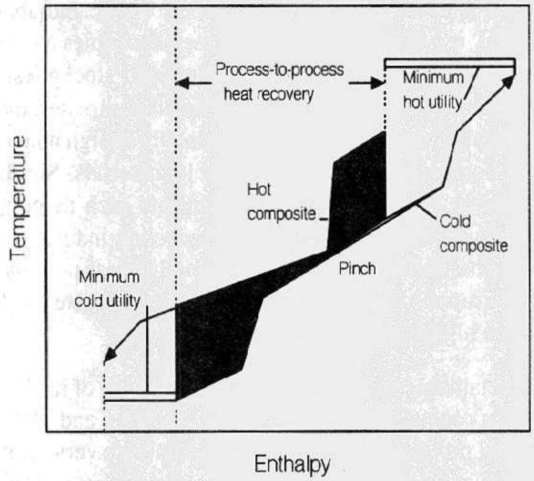

Fig. 2 : Thermal pinch analysis.

In the hierarchical method, the logical sequence of flowsheet evolution provides a framework for identifying and evaluating the waste and pollutants minimisation options. The overall problem is successively decomposed into smaller problems. Design alternatives for each of these are evaluated and appropriate choices are made. The proper decomposition of the problem with the objective in mind is the key to this method. The other methods in this category or knowledge based approaches include methods in which specific pollution prevention ideas are transferred directly from one application to others.

The mathematical approaches can be of either analysis type or synthesis type. In the former, an existing process is analysed using the process models and a better design is sought by making alterations to the existing design. On the other hand in the process synthesis, an optimal design is found out from a large number of alternatives using mathematical methods. The difference between the two approaches may be understood, considering that the former pertains to local or limited optimisation, whereas the latter is global.

The thermodynamic method or pinch analysis is based on the concept that in most cases the plots of enthalpy as function of temperature of hot streams or heat sources and cold or sink streams show a pinch point, i.e., at one temperature both the streams have almost the same enthalpy. Fig. 2 schematically shows the enthalpy - temperature diagram of hot and cold streams and the pinch point (The existence of thermal pinch point in the blast furnace process is well known).

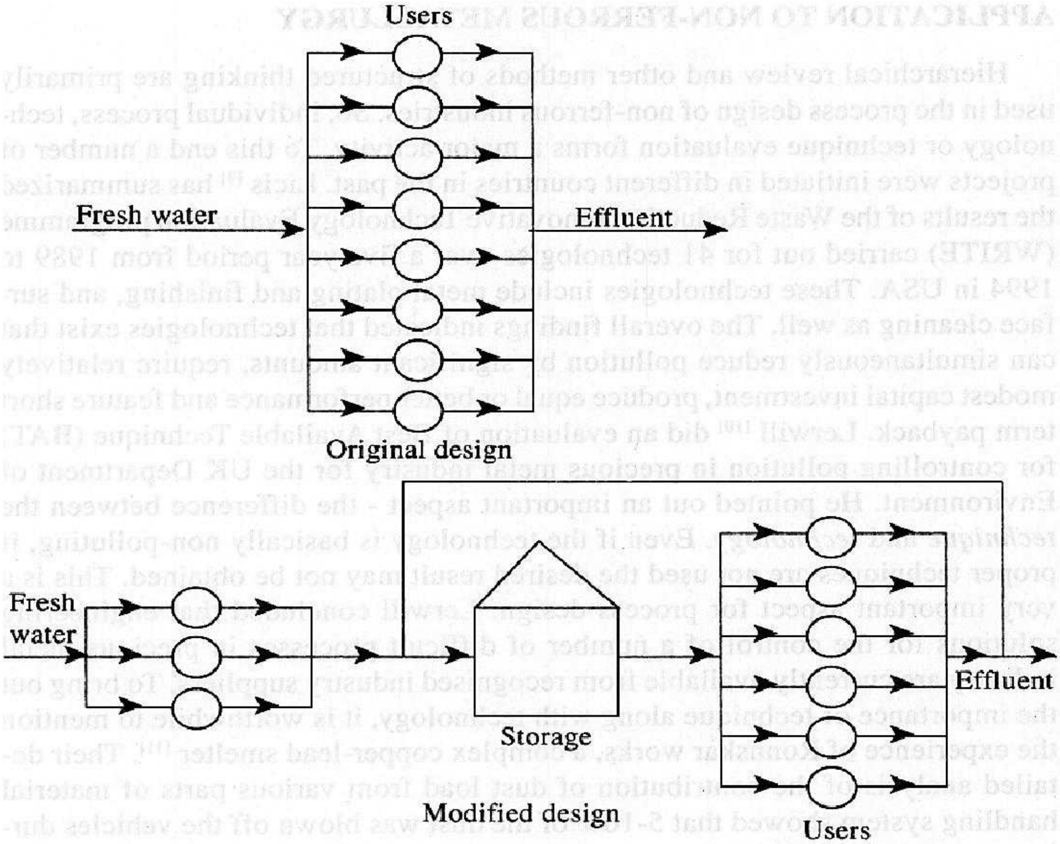

Fig. 3 : Design modification by waste water pinch procedure.

In the absence of chemical reactions, pinch point represents a restriction in the flow of heat within the process and sets a practical limit on the amount of heat that can be recovered. In the environmental context, this approach is useful primarily to reduce energy consumption and thereby reduce the levels of NO_x, SO_x and CO_2. Pinch analysis has been extended to mass transfer also. In this case, the concentration of contaminants vs mass of streams are plotted for inlet and outlet streams to find out the pinch points. The method has been effectively used to reduce water consumption and thereby increase the contaminant concentration in the effluent [6]. The increased concentration of contaminant and lower volume of the effluent, quite often, make the treatment of effluent, to recover or neutralize the contaminant, possible. Fig. 3 schematically shows the original and the modified process design obtained by the pinch analysis for reduction of water consumption in a process. The pinch analysis or pinch technology has been widely used to devise effective ways to accomplish reduction of wastes and gaseous emissions particularly for chemical industries [7-8].

APPLICATION TO NON-FERROUS METALLURGY

Hierarchical review and other methods of structured thinking are primarily used in the process design of non-ferrous industries. So, individual process, technology or technique evaluation forms a major activity. To this end a number of projects were initiated in different countries in the past. Licis [9] has summarized the results of the Waste Reduction Innovative Technology Evaluation programme (WRITE) carried out for 41 technologies over a five year period from 1989 to 1994 in USA. These technologies include metal plating and finishing, and surface cleaning as well. The overall findings indicated that technologies exist that can simultaneously reduce pollution by significant amounts, require relatively modest capital investment, produce equal or better performance and feature short term payback. Lerwill [10] did an evaluation of Best Available Technique (BAT) for controlling pollution in precious metal industry for the UK Department of Environment. He pointed out an important aspect - the difference between the *technique* and *technology*. Even if the technology is basically non-polluting, if proper techniques are not used the desired result may not be obtained. This is a very important aspect for process design. Lerwill concluded that engineering solutions for the control of a number of difficult processes in precious metal industry are currently available from recognised industry suppliers. To bring out the importance of technique along with technology, it is worthwhile to mention the experience of Ronnskar works, a complex copper-lead smelter [11]. Their detailed analysis of the contribution of dust load from various parts of material handling system showed that 5-10% of the dust was blown off the vehicles during transportation, while as much as 10-20% was lost because the vehicles were overloaded. However, by far the most important one, 50-70% of the total, was the material stuck at truck wheels at the storage areas and then spread on the road. The contribution from mounds of stored materials was normally negligible, but dominated on windy days. The usual preventive methods of speed limit, no overloading, restrictions on unnecessary movement of vehicles and road cleaning brought down the dust load significantly. However, to reduce the volume of contaminated water which is essential for its successful treatment, both technique and technology were used. Motivating the people so that they use less water in the process technique, and evaporation technology were found to give the desired result. The later step was decided after the process analysis.

CHALLENGES AND OPPORTUNITIES FOR POLLUTION CONTROL AND WASTE MINIMISATION IN NON-FERROUS METALLURGICAL INDUSTRIES

A complete waste management system today must include waste reduction, reuse and recycling components commonly referred to as the 3R's, in addition

Table 1 : Approximate tonnages of waste generated during processing [12] (1996-1997 statistics)

Metal	Average feed grade	Average concentrate grade (%)	Ore/Metal Production	Waste generated in processing (tonnes)
Au	4 ppm	—	2710 kg (Au)	6,77,500
Al	—	—	Bauxite: 59,31,000 (t)	Red mud: 30,00,000
Cu	1.03%	21.2	38,95,000 (t)	30,69,260
Pb	2.15%	56.97 }	22,64,000 (t)	20,14,960
Zn	8.07%	53.99 }		

Table 2 : Estimated values of energy requirement, capital cost and sulfur containment for alternative technologies [13]

Technology	Estimated values		
	Maximum Sulfur Containment (%)	Capital cost (% of base case)	Energy requirement (% of base case)
Green feed reverberatory	52	90	106-116
Calcine feed reverberatory	86-93	100	100
Electric furnace	94-95	100	106-156
Outokumpu Flash Furnace	94-95	70-80	56-79
Inco Flash Furnace	94-95	70-80	64-67
Noranda	94-95	80	53-74
KIVET	94-95	70-80	78
Mitsubishi	98-99+	70-80	78-90
QS	98-99+	70-80	68
WORCA	98-99+	70-80	78

to disposal methods such as landfill and incineration. The challenges facing the non-ferrous metallurgical industries towards mitigation of pollution caused by process gas and dust emissions, effluents and solid wastes are relatively more severe compared to the ferrous metallurgical processes. As highlighted earlier, substantial amounts of solid wastes are generated right from the mining stage itself in non-ferrous processing due to the small amounts of metal values present in the natural ore bodies. Typical estimates of solid wastes generated in some non-ferrous metallurgical operations are given in Table 1 [12]. Let us now examine some recent developments and options available for pollution abatement. In non-ferrous smelting industry emission of sulfur dioxide forms one of the major environmental issues. As early as 1981, Burckle and Worrell [13] compared the sulfur contaminant scenario along with the investment and energy requirement for various process alternatives. Table 2 summaries the results compiled by them. It clearly shows that all recent technologies are inherently less polluting and less energy intensive. Kojo and Hanniala [14] of Outokumpu Engineering Contractors Oy, state that a new smelter based on the Outokumpu Flash Smelting/Flash converting technology captures 99.9% input sulfur and has set environmental standards for copper smelters. Table 3 shows the levels of emission that could be achieved in copper and aluminium smelting using the best available technology till 1992 [15]. It is obvious that in primary metal production, technologies are available, which are environmentally acceptable at least as far as dust and gaseous pollutants are concerned.

Table 3 : Emissions and energy achievable by the application of best available technologies [15]

Parameter in Air (kg/ton product)	Copper	Aluminium
Dust	0.1	1.00
SO_2	3.5	1.00
NOx	0.5	0.05
Total fluorides	—	0.03
Energy (kwh/ton)	2000	13000

Liquid Effluents

To meet the effluent limit standards for water quality, the options pertain to the selection of the best available technology (BAT), failing which the Best Practicable Technology (BPT) is adopted. It is worthy to mention that bio-remediation techniques are gaining in importance. For example, while cyanide is eventually toxic to all life forms, some microorganisms such as bacteria, algae and fungi can tolerate and even metabolise cyanide at fairly elevated levels (upto 200 ppm). A bacterium, *Pseudomonas stuzeri* has been discovered that can degrade carbon tetrachloride, a widely used toxic chemical. [16] The potential applications of microbial remidiation are huge, particularly in waste water treatment, as a detoxified end product results. In such endeavours, cloning and adaptation techniques are being increasingly adopted to manipulate microbial systems to perform a designed function.

Solid Wastes

The disposal of unstable (leachable) solid wastes which is primarily formed in hydrometallurgical operations or the sludge or precipitates obtained from the treatment of liquid effluent is a major problem since ponding, the usual practice, is not very satisfactory one from the environment point of view. However, even in this area a number of technological options are available. So what is needed is proper integration of technologies and techniques in the process design to get the desired result. Castle and Emery [17] have discussed the process flowsheet options for the extraction of copper and zinc from primary concentrate while meeting the projected standards of air emission, effluent and solid waste discharge. They have discussed the technical problem with regard to the treatment of secondary zinc residues.

Considering the large quantities of solid wastes generated during mining and processing, it appears that complete utilisation of such huge impoundments would be a herculean task. In this context, afforestation techniques adopted by Hindustan Zinc Limited [18] and Kolar gold mines deserve special mention. Adapting the vegetation to grow under adverse conditions through directed evolution and genetic engineering would result in synergy between man and nature. After several billion years it is no surprise that nature has a thing or two to teach mankind about waste deposal.

Metal Finishing and Plating

Mathematical approaches for waste minimisation have been successfully used to a limited extent only for the metal finishing process. Smith and Schurig [19] developed a detailed material balance model for a chrome plating plant and used it to evaluate various waste minimization options. Lusinchi et al [20] also simulated the nickel/chrome electroplating line by a material balance model and showed that it could be effectively used for waste minimization. One of their process configuration shows a very interesting possibility, zero discharge of chemicals in water .

CONCLUSION

The process engineering approaches for pollution control and waste minimisation should enable the proper selection and integration of existing technologies to achieve the desired results with optimum capital and energy costs. Industrial ecological practices will facilitates minimisation of waste and thus ensure better harmony with nature. It is expected that the future non-ferrous industries will be environmentally benign, frugal on energy use, highly flexible in operation and will exploit synergies with other industrial systems.

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