WASTE MINIMIZATION IN METAL FINISHING INDUSTRIES

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Summary

Metal finishing operations are carried out by most of the industries engaged in forming and finishing metal products. The wastes from metal finishing industries include cleaning acids, sludge containing toxic heavy metals, solvents and oils, and spent chromate and cyanide solutions, which are classified as hazardous substances. Treatment of hazardous wastes is not only tedious, but also involves huge costs. Alternately, waste minimization approach that involves adoption of technological and management options to reduce or avoid generation of wastes leads to both environmental as well as economic benefits. Introduction of waste minimization practices in metal finishing industries can result in reduction of total quantities of hazardous wastes generated by the industry as a whole. The economic viability of applicable waste minimization techniques depend on factors such as cost of water, cost of disposal, value of materials recovered. Case studies illustrated in this paper clearly establish that in most cases, waste minimization practices, apart from being environment friendly, are economically profitable.

1. Introduction

In the era of industrial growth and economic development, the concept of waste minimization stems from the need to "produce better while polluting less" in order to avoid environmental damages that may affect quality of life in short and medium terms, and threaten the survival of living beings on the planet, in longer terms. The basic goal of waste minimization is to eliminate formation of byproducts which are discarded as wastes and harm the environment. Waste minimization techniques in industrial production processes aim to avoid production inefficiencies, which results in excessive waste generation. Waste minimization assumes more significance when the wastes generated in an industry are "hazardous" in nature, because treatment of hazardous wastes is tedious, as they are not readily amenable to treatment, and involve huge costs. Moreover, improper disposal of hazardous wastes may cause irreparable environmental damages in shorter terms.

Hazardous wastes in an industry can be generated directly as a by-product, and also as a result of treatment of wastes. In case of metal finishing industries, hazardous wastes are generated in both of these ways. Hence, metal finishing industries are regarded as major generators of hazardous wastes in many industrialized nations. Waste minimization in metal finishing industries helps to reduce hazardous waste generation, and hence the cost of treatment and disposal. This article briefly reviews major metal finishing operations and characteristics of waste streams from these operations. While identifying opportunities for waste minimization, proven techniques and their practical implementation in many industries around the world are presented. Two feasibility studies, one on a metal plating unit in Thailand, and another on metal pickling units in India, conducted for assessing pollution minimization potential, are discussed.

2. Metal Finishing Operations

Metal finishing operations are carried out by most of the industries engaged in forming and finishing metallic products. Metal finishing involves alteration of the metal workpiece's surface properties in order to increase the corrosion or abrasion resistance, alter appearance or to enhance the utility of the manufactured product. Most metal finishing operations have three basic steps, namely:

(i) surface cleaning or preparation;
(ii) surface treatment, that involves coating a layer of another metal, paint, plastic etc., or changing the surface properties;
(iii) rinsing and drying.

Metal finishing operations can be broadly classified into three major categories as follows:

1. Chemical and electrochemical conversions.
2. Diffusion coating techniques.
3. Case-hardening techniques.

Chemical/ electrochemical conversions	**Diffusion coating operations**	**Case-hardening operations**
• Phosphating • Chromating • Anodising • Passivation • Metal coloring • Electroplating	• Lattice diffusion • Spraying • Cladding • Vapour deposition • Vacuum coating • Hot dipping	• Carburising • Carbo-nitriding • Nitriding • Micro-casing • Thermal hardening

Table 1. Categories of metal finishing operations.

2.4. Chemical and Electrochemical Conversions

Chemical and electrochemical conversions are designed to deposit a coating on a metal surface that performs a corrosion protection and/or decorative function, and in some instances for preparation for painting. These processes include phosphating, chromating, anodising, passivation and metal colouring.

Phosphating treatments provide a coating of insoluble metal phosphate crystals that adhere strongly to the base metal. The main function of the coating, due to its absorptivity, is to act as a base for the adhesion of paints, lacquers and oils to the metal surface. They also provide corrosion resistance to some extent.

Chromating is to minimize rust formation and to guarantee paint adhesion.

Anodising employs electrochemical means to develop a surface oxide film on the work-piece, thereby enhancing its corrosion resistance.

Passivation is a process by which protective coatings are formed through immersion of the work-piece in an acid solution.

2.5. Case-hardening

Case-hardening operations produce a hard surface (case) over a metal core that remains relatively soft. The case is wear resistant and durable, while the core is left soft and ductile. Case hardening methodologies include carburising, carbo-nitriding, nitriding, cyaniding, microcasing and thermal hardening.

The most widely used case hardening operation, **carburising**, involves diffusion of carbon into a steel surface at temperatures of 845°C to 955°C, producing a hard case in the high carbon areas.

Nitriding processes diffuse nascent nitrogen into a steel surface to produce case hardening. It is normally accomplished through use of either nitrogenous gas (usually ammonia) or a liquid salt bath, typically consisting of 60% to 70% sodium salts (mainly sodium cyanide) and 30% to 40% potassium salts (mainly potassium cyanide).

Carbo-nitriding and **cyaniding** involves the diffusion of both carbon and nitrogen simultaneously into a steel surface.

Thermal hardening methods are those that generate a case through localized heat and quenching, rather than through chemicals. Very rapid heat application results in surface hardening with little heat conducted inward. Since no carbon or nitrogen is diffused into the work-piece, it is the existing carbon content of the ferrous metal that determines the hardness. The heating is accomplished through electromagnetic induction, high temperature flames or high velocity combustion product gases.

2.6. Diffusion Coating

Diffusion coating provides a layer that changes the surface properties of the work-piece to those of the metal being applied (diffused). The work-piece becomes a composite material with properties generally not achievable by either material singly. The coating functions as a durable, corrosion-resistant protective layer, while the core material provides the load-bearing functions. In this process, the coating is achieved through contact or exposing the base metal to the coating metal at elevated temperatures allowing lattice inter-diffusion of the two metals. Alternately, spraying techniques, cladding (application of mechanical techniques), vapour deposition and vacuum coating are also used.

Hot dipping is a diffusion process that involves partial or complete immersion of the work-piece in a molten metal bath. Common coating materials include aluminum, lead, tin, zinc and the combinations of the above. The coating metal in a **cementation diffusion** process is applied in powdered form at high temperature (800°C to 1000°C), in a mixture with inert particles such as alumina or sand and a halide activator. The main applications of **spray diffusion** coatings are for workpieces difficult to coat by other means due to their size and shape, or that damaged by the high temperature heating. **Vapor deposition** and **vacuum coating** produce high quality, pure metallic layers, and can sometimes be used in place of plating processes. A layer of metal cladding can be bonded to the work-piece using high pressure welding or casting techniques

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Biographical Sketches

M. Sundaravadivel is an Environmental Engineer with the Central Pollution Control Board, Ministry of Environment and Forests, Government of India. He has been working in the field of industrial pollution control since 1989, particularly in the area of waste minimization and cleaner production in agro-based industries and small-scale metal finishing industries. He has also been an engineering consultant for planning, design and development of wastewater collection and treatment systems for a few large cities of India. Currently, he is engaged in research on technology, economic and policy aspects of liquid and solid waste management in small and medium towns of developing countries in the Graduate School of the Environment, Macquarie University, Sydney, Australia.

S. Vigneswaran is currently a Professor and Head of Environmental Engineering Group in Faculty of Engineering, University of Technology, Sydney, Australia. He has been working on water and wastewater research since 1976. He has published over 175 technical papers and authored two books (both through CRC press, USA). He has established research links with the leading laboratories in France, Korea, Thailand and the USA. Also, he has been involved in number of consulting activities in this field in Australia, Indonesia, France, Korea and Thailand through various national and international agencies. Presently, Dr. Vigneswaran is coordinating the university key research strengths on “water and waste management in small communities”, one of the six key research centers funded by the university on a competitive basis. His research in solid liquid separation processes in water and wastewater treatment namely filtration, adsorption is recognized internationally and widely referred.

C. Visvanathan, is an Associate Professor of the Environmental Engineering Program, School of Environment, Resources and Development, Asian Institute of Technology. He has a Ph.D. (Chemical/Environmental Engineering) from Institute National Polytechnique, Toulouse, France. His main areas of research interests include: Solid–liquid separation technologies for water and wastewater treatment, waste auditing and cleaner production and solid waste disposal and management. Dr. Visvanathan has published more than 50 international journal and conference papers. His professional experiences include: Project Engineer, Asia Division, International Training Center for Water Resources Management, Sophia Antipolis, France, and short term consultant to UNEP Industry and Environment Office, Paris, France.