Anthropogenic Contamination of Ecosystems

Minimising Industrial Wastes from the Fabricated Metal Products Industries

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Introduction

The fabricated metal products and machinery sector in Illinois employs over 80,000 people. The sector includes farm machinery, packaging machinery and construction machinery. Illinois also has many highly specialized niches within the fabricated metals sector in areas such as bolts, nuts, screw and rivet, spring, and crown and closure manufacturing. Additionally, there are a number of specialized small/machine fabrication shops that cater to automotive industry Tier I and Tier II suppliers. Collectively, these areas represent a dominant sector of the Illinois economy and form part of the Advanced Manufacturing Cluster, a strategic sector targeted for growth by the State of Illinois. Contrary to popular belief, these old economy industries are by no means low-tech industries. Instead, they have sought to foster and embrace innovations to maintain global competitiveness. Even more noteworthy is that these industries form the bedrock on which the new economy industries such as telecommunications and biotechnology are anchored. Examples of the latter are the critical role micro-machined components and dedicated machinery such as gene sequencers play in the “new economy” sectors.

The fabricated metal products industries sector engages in the forming/shaping of metals and their surface preparation. While a large variety of alloys are processed in these facilities, they can be broadly categorized as ferrous and non-ferrous. Surface preparation includes a myriad of operations that range from electroplating to powder coating. The primary markets served by this sector include automotive, electronics, aerospace and consumer durables among others (US EPA, 1995).

Metals usually are shipped in bulk as sheets, rods, wires and tubes. A smaller fraction is shipped as castings. Once received at the manufacturing facility, these materials are further shaped. Examples of shaping processes include shearing, punching, stamping, and coining among others. While the details of the processes vary (SME, 1984), they enable the transformation of the bulk metal to a predetermined shape. Castings differ as the metal is shaped to closely approximate the final form through molding of molten metal. In a number of plants, several such forming operations may be necessary to produce a final product. In addition to these operations, many processes categorized as machining are also frequently part of the manufacturing process. These include drilling, milling, turning and the like. These processes accomplish their objective through precise removal of metal and are termed metal removal processes.

In addition to basic forming/shaping processes, the surfaces of the metal parts are frequently manipulated in

<table>
<thead>
<tr>
<th>Process</th>
<th>Material input</th>
<th>Air emission</th>
<th>Process wastewater</th>
<th>Solid waste</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metal shaping</td>
<td>Cutting oils, degreasing and cleaning solvents, acids, alkali and heavy metals</td>
<td>Solvent wastes</td>
<td>Waste oils, spent acid, alkaline and solvent wastes</td>
<td>Metal chips, solvent still bottom wastes, metal bearing cutting fluid sludge</td>
</tr>
<tr>
<td>Surface preparation</td>
<td>Solvent degreasing, alkaline and acid cleaning</td>
<td>Solvents, alkali, acids</td>
<td>Solvent, alkaline and acid waste</td>
<td>Ignitable wastes, solvent wastes, still bottoms</td>
</tr>
<tr>
<td>Anodizing</td>
<td>Acids</td>
<td>Metal-ion bearing mists and acid mists</td>
<td>Acid wastes</td>
<td>Wastewater treatment sludge</td>
</tr>
<tr>
<td>Chemical conversion coating</td>
<td>Metals and acids</td>
<td>Metal-ion bearing mists and acid mists</td>
<td>Metal salts, acid and base wastes</td>
<td>Spent solutions, wastewater treatment sludge</td>
</tr>
<tr>
<td>Electroplating</td>
<td>Acid/alkaline solutions, heavy metal bearing solutions, cyanide bearing solutions</td>
<td>Metal-ion bearing mists and acid mists</td>
<td>Acid/alkaline cyanide and metal wastes</td>
<td>Metal and reactive wastes</td>
</tr>
<tr>
<td>Painting</td>
<td>Solvents and paints</td>
<td>Solvents</td>
<td>Solvent wastes</td>
<td>Still bottoms, sludge, paint solvents</td>
</tr>
</tbody>
</table>

Various ways to enhance functional properties. One common operation is painting. Other examples include electroplating, electroless plating, anodizing and phosphating. These surface treatment operations frequently require the surfaces themselves to be clean prior to application or adhesion can be impaired and functionality compromised. Solvents, alkali, and acids are used in immersion, spray, or pickling processes to achieve cleanliness.

The combination of operations enumerated above and the use of energy in the form of compressed air, electrical motors, hot air, hot water/steam and the like result in gaseous, liquid, and solid effluents. It is the object of this chapter to illustrate with a few examples some ways to minimize the generation of these wastes.

**Common Industrial Wastes in the Fabricated Metal Product Industries**

The most common wastes arising from the fabricated metal products sector are metal, paint, electroplating sludge, sludge from various processes, acids, alkali, used industrial fluids, volatile organic compounds, water, and combustion products such as CO₂. The common processes and the wastes associated with them are shown in Table 31.1 (US EPA, 1995).

**Minimizing Waste**

A useful tool for achieving waste minimization is to recognize that every situation can be reduced to four elements: people, process, management controls, and externalities (Figure 31.1).

This, of course, is a variation on the Materials, Machines, People, and Methods approach used in the fish bone cause and effect diagrams in problem solving. However, the terminology used in Figure 31.1 is more descriptive of the issues identified by our interactions with our clients over a decade and will be used instead.

The major categories contributing to waste as identified in Figure 31.1 must be disaggregated to provide a finer degree of detail. More importantly, the degree of detail should be no finer than required to promote efficient problem solving.

A brief definition of the terms used in Figure 31.1 is provided to familiarize the reader with the scope intended with their use.

- **Waste**: As used in this document and consistent with its focus, waste will primarily refer to materials (including water and energy) lost to the environment.
• **Process:** Pertains to the materials and mode of manufacture used to transform raw materials to final products capable of achieving predetermined functional and aesthetic attributes
• **Management System:** All aspects of the system that direct and/or support the transformation of raw materials to final products. A nonexclusive list is management organization and style, accounting systems, logistics, purchasing culture, and interface with the supplier base.
• **People:** Those directly involved in the operation of the machinery or process that transforms raw materials to products.
• **Externalities:** These refer to constraints imposed on the industry by external parties. Typically these are regulations that govern environmental discharges, health and safety conditions, customer-mandated manufacturing processes etc.

In the following section, we illustrate with hypothetical examples ways of leveraging the above to minimize waste.

**Illustrative Examples of Waste Minimization**

**Leveraging Management Systems to Minimize Waste Metalworking Fluids**

Metalworking fluids are used in most metal cutting operations to provide cooling, lubrication, corrosion protection and chip removal. The correct choice and application of metalworking fluids is critical for modern high-speed machining operations. In the past, most metalworking fluids were oil based. However, in the U.S.A most metalworking fluids are oil/water emulsions, a use motivated in part by safety but also due to the ability to combine both cooling and lubrication in a single fluid. These advantages are balanced by the increased need for close monitoring and chemical expertise for preventive maintenance. For example, the contamination of these fluids by bacteria can cause selective degradation of important functional components of the fluid formulation such as corrosion inhibitors. Other examples include the accumulation of ions such as calcium and magnesium leading to emulsion destabilization and loss of lubrication. The increased complexity in the management and maintenance of these water based metalworking fluids leads to both increased waste volume and increased manufacturing costs. It has been estimated that for every dollar spent on metalworking fluid purchases, $1.5-5.5 are spent on managing, maintaining, and disposal (Bierma and Waterstraat, 2004).

**Problem Recognition and Root Cause Analysis**

Given the above as background, let us turn our attention to a situation often encountered in a fabrication facility. In this hypothetical example, a plant has identified increased volume of metal working waste as an issue. Discussions with plant personnel reveal that fluid breakdown and oil contamination lead to frequent disposal. The problem of oil contamination is traced to leaking hydraulic oil valves and fluid breakdown caused by use of water of high hardness. Both are examples of process related issues. Fluid breakdown and oil contamination are also recognized as facilitating increased bacterial growth and associated problems such as dermatitis. Moreover, it is also discovered that a few central sumps supply many of the machining centers. A few of the machining centers are sources of regulated heavy metals. In an effort to keep these metals from exceeding thresholds triggering hazardous waste classification, and to combat worker complaints related to dermatitis, the plant had adopted a strategy of pumping the fluids out on schedule rather than performance. Both the dermatitis and the hazardous waste limits are examples of externalities encountered in manufacturing plants. Further discussions with operators reveal that fluids are mixed at improper concentrations, rarely monitored for concentration, and the central sumps
are viewed as convenient reservoirs for plant trash. All of these are examples of lack of awareness on the part of the operators about the interconnectedness between the metalworking fluid sumps and product quality. These are examples of people related issues. Finally, a review of the management systems reveals that purchases are made on a per gallon or pound basis, often on first price alone. No comprehensive cost accounting practices are in place. These are examples of management system problems.

Solution
Having identified many of the important causes (Figure 31.2) contributing to the waste issue, the plant realized the need for a comprehensive approach to improve the situation.

The plant lacked the knowledge and technical resources to comprehensively address these issues on its own, although it was recognized that the supplier of the chemicals had the resources and the knowledge to comprehensively address all of the identified issues (Figure 31.3). However, the plant personnel had doubts about turning over this portion of the operation to the chemical supplier. Opposition was particularly vocal from the purchasing department as they believed this would increase costs. To address this concern, the plant decided to restructure the relationship between the plant and the supplier from an adversarial one to one of shared partnership. This was accomplished by a contractual shift that eliminated the purchasing of fluid to one that purchased “fluid performance.” Under the new contract, the supplier was paid a flat fee for supplying “metalworking fluid performance” based on historical costs. Furthermore, the plant also negotiated a targeted reduction in costs for subsequent years. Under the new contractual agreement, the
chemical supplier “owned” the fluids and did not get paid on a per gallon basis. The supplier stood to make additional profits through reducing chemical use within the plant while still providing performance. This contractual agreement aligned the interests of both the plant and the supplier and allowed the plant to leverage the expertise of the supplier.

The scenario sketched out above is not a flight-of-fancy. It has been tried successfully at several large corporations and is called Chemical Management Systems (Table 31.2). Some examples of successful implementation in Illinois are provided in Bierma and Waterstraat (1997).

The above example of aligning supplier interests with facility interests is one of many options available to leverage management systems to minimize waste. Others include adopting frameworks for holistic planning and decision-making, instituting transparent and well thought-out Total Management Accounting systems that pinpoint process inefficiencies, and encouraging a culture of constant improvement and personnel development.

**Leveraging Process Improvements – An Electroplating Example**

Electroplating, the process of depositing metal over a substrate through the use of electricity, is a commonly used technique to obtain both functional and decorative finishes. An example of a functional finish is chromium deposition for corrosion resistance. Achieving an antique brass finish on a steel part is an example of a decorative finish.

Quality coatings can only be achieved if the parts are cleaned thoroughly prior to being plated. Cleaning is accomplished using alkaline solutions formulated with surfactants to achieve removal of tenacious oil films and other types of soils. Following this, the surfaces are rinsed and then processed through acid solutions to remove oxide scales. Residual acid is removed by rinsing. Finally, the parts are plated, rinsed and subjected to further processing as desired. Electroplating can be done from both alkaline and acidic solutions.

The movement of parts through the sequence of steps results in carry-over of solutions from the chemical tanks to the rinse tanks. The carry-over causes contamination of the rinse tanks with acids and alkali. Rinsing ability is compromised as contaminants accumulate in rinse tanks. To counter the build-up of contaminants, the rinse water is bled either periodically or continuously and replaced with fresh water. As the rinse tanks contain hazardous metals and metal complexing agents such as cyanide, they require treatment prior to discharge. These treatments frequently are pH adjustment followed by heavy metal precipitation. Treatment for hexavalent chromium tends to be more complicated. In all these cases, the sludge formed is deemed hazardous and disposal is expensive.

**Problem Identification and Root Cause Analysis**

In the example, we illustrate the utility of leveraging process improvements in an electroplating shop (Figure 31.4).

An electroplating job-shop in Chicago, IL was experiencing difficulties with higher cost of electroplating

<table>
<thead>
<tr>
<th>Plant</th>
<th>What is managed?</th>
<th>Contract</th>
<th>Resultant benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Navistar International, Melrose Park, Illinois</td>
<td>Metalworking fluids, cleaners</td>
<td>Fixed fee staffing level/staffing fees</td>
<td>Metalworking fluid usage reduced by 50%; Waste haulage reduced by 90%; Reduced production downtime; Improved product quality reduced engine block and head rework 93%</td>
</tr>
<tr>
<td>Ford Assembly Plant Chicago, IL</td>
<td>All fluids except paints, sealers, adhesives All solvents</td>
<td>Fee/vehicle for solvent; Fee/vehicle for other chemicals; Fixed annual fee for chemicals unrelated to production</td>
<td>VOC (volatile organic emission) reduced by 57% Wastewater sludge reduced by 27%</td>
</tr>
<tr>
<td>Chrysler, Assembly Plant, Belvidere, IL</td>
<td>All chemicals for cleaning, treating, and coating autobody</td>
<td>Fixed fee/vehicle</td>
<td>Over $1 million in first year; dramatic reductions in VOC, improved product quality, improved health and safety</td>
</tr>
</tbody>
</table>
sludge disposal. The shop specialized in plating fasteners and other small parts. These are typically barrel-plated. A root-cause analysis of the situation identified “drag-out” as a leading contributor to the stated problem. Additional queries led to identifying various other factors as secondary contributors: barrel design, viscosity of solution, part-fill quantity, drain-time among others.

Solution
Suggestions to improve the situation included: reducing plating bath solution concentration and increasing temperature to reduce viscosity, increasing drain-time to allow adequate drainage, and reducing unnecessary hold-up through careful part-filling. These were implemented and found to be successful in improving the situation. The remaining question was whether the barrel design could be improved to reduce drag-out even further. To test this, four barrel designs were evaluated with the results shown in Figure 31.5.

Compared to the barrel that was being used (Type A), barrels C and D resulted in 25% reduction in carry-over. The estimated reduction for that facility was 11,000 Liters of various solutions used in the process.

Leveraging process systems requires fine-grained knowledge about the underlying physics of the process. Such knowledge can be scarce in many instances. Even when it exists it is scattered across several disciplines in the literature. Falling within the realm of applied research,
it is also found more in specialized trade literature than in the more easily accessible peer reviewed scientific literature. Again, suppliers can be surprisingly knowledgeable about some of these systems and should be consulted when solving such problems.

**Leveraging Externalities**

In this example, we illustrate how externalities such as environmental regulations can influence process waste.

A company manufactures several parts, including an automotive component. The relationship with the auto manufacturer is considered important for strategic reasons and cultivated zealously. Initially 100% of the parts processed are ferrous and typically go through the same processing steps including phosphating. No chromium or cyanides are used in the process and the process typically is well controlled. The wastewater from the facility is treated in a central facility and the metal precipitated. The sludge is dewatered and shipped to another facility where it is converted to phosphate glass.

The automotive company requests that the manufacturer process aluminum parts in an effort to reduce the weight of the final vehicle. However, this caused a regulatory dilemma to the manufacturer. Under USEPA regulations, the sludge produced from the phosphating of aluminum is designated a hazardous waste. Ironically, USEPA's original intent was to regulate outdated processing practices that utilized chromium and cyanide solutions; a practice not in use at the manufacturer. Furthermore, contamination of a large quantity of non-hazardous waste sludge with a small amount of a classified hazardous waste would require the entire waste sludge material to be classified as hazardous and disposed of accordingly. This of course would increase disposal costs, compliance activity, and create potential legal liability.

**Solution**

Under these circumstances, the manufacturer had two options. One was to segregate the aluminum phosphating line from the rest and treat it separately and deal with the resulting sludge as a hazardous waste. The second was to characterize the aluminum sludge for hazardous characteristics, prove its nonhazardous nature, and petition the government for delisting or relief from the law. The first option creates an extra cost. The second option involves both cost and time. In this example, a combination of the first and second option was the preferable approach to achieve waste minimization. Combining the two sludges would have prevented the beneficial reuse of the ferrous sludge material.

Examples such as this that highlight the unintended consequences of well-intentioned laws are not uncommon but do pose a problem for manufacturers and in some cases can increase waste generation.

**Conclusions**

The Illinois Sustainable Technology Center (ISTC) has over the past twenty years worked with numerous metal fabricators and machinery manufacturers within Illinois assisting them with reducing manufacturing costs through greater process efficiency. These efforts have helped reduce use of fresh water, manufacturing energy intensity, volatile organic emissions in the Greater Chicago Metropolitan area, heavy metals, and nutrients release to Illinois rivers and Lake Michigan, hazardous wastes and sludges to Illinois landfills, and increased worker health and safety through encouraging adoption of green processes in manufacturing. Select examples of success can be found in the various annual reports of the ISTC (http://www.istc.illinois.edu/) and the annual Illinois Governors Pollution Prevention Award lists.

Strategies adopted to achieve this level of success include a sector approach to pollution prevention, partnerships with the IEPA (Illinois Environmental Protection Agency) and local wastewater treatment agencies, and trade associations. ISTC relies on the problem solving approach outlined here as the underpinning of its broader waste minimization strategy. This approach is crucial to achieving plant level success. Achieving sustained improvements in manufacturing efficiency and waste minimization requires constant technological innovation and an ability to leverage advances from unrelated sectors. Organizations such as the ISTC fulfill this critical role of “cross-pollination.”

In conclusion, the fabricated metal products industry is diverse, incorporating many different processes and materials. Many of these operations have the potential
to generate waste if incorrectly operated, poorly managed or over regulated. It would be unwieldy to provide suggestions and solutions for waste minimization under every possible scenario. Hence, our focus in this document was on the problem solving approach to achieving waste minimization. That being said, there are many excellent sources of information on specific ways to reducing waste within this industry, a few of which are listed as starting points for further reading.
Further Reading:


Chapter 30


LandSim. http://www.landsim.co.uk


US, the Resource Conservation and Recovery Act (RCRA; PL# 94-580)


Chapter 31


Bierma, T.J. and Waterstraat, F.L. 2004. Total cost of ownership for metalworking fluids. WMRC Reports, RR-105, Champaign, IL.


Further Reading:


Chapter 32


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