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Project Summary

Waste Minimization Audit Report: Case Studies of Minimization of Solvent Waste from Parts Cleaning and from Electronic Capacitor Manufacturing Operations

To promote waste minimization activities in accordance with the national policy objectives established under the 1984 Hazardous and Solid Waste Amendments to the Resource Conservation and Recovery Act of 1976 (RCRA), the Hazardous Waste Engineering Research Laboratory (HWERL) of the USEPA Office of Research and Development has undertaken a project to develop and test a waste minimization (WM) audit procedure.

As part of this project, a total of 6 WM audits were carried out in four separate facilities. This report presents the results of an on-site WM audit performed at an electronic capacitor manufacturing facility for solvent wastes. The report also describes the WM audit procedure as it has developed from the initial (pre-project) sequence of steps, to the modified (post-project) sequence that reflects the experience gained during this HWERL project.

This Project Summary was developed by EPA's Hazardous Waste Engineering Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

To promote waste minimization activities in accordance with the national policy objectives established under the 1984 Hazardous and Solid Waste Amendments to the Resource Conservation and Recovery Act of 1976 (RCRA), the Hazardous Waste Engineering Research Laboratory (HWERL) of the USEPA Office of Research and Development has undertaken a project to develop and test a waste minimization (WM) audit procedure.

As part of this project, a total of 6 WM audits were carried out in four separate facilities. The full report presents the results of the on-site WM audits performed at two facilities that generate solvent-bearing wastes. It also describes the WM audit procedure as it has developed from the initial (pre-project) sequence of steps, to the modified (post-project) sequence that reflects the experience gained during this project. The 4 other audits, 2 dealing with cyanide wastes and 2 dealing with heavy metal and corrosives wastes, are discussed in two separate reports.

Waste Minimization Audit Procedure

The main objective of the full report is to provide useful guidelines for the conduct of a WM audit. The following sections discuss how a WM audit fits into an overall WM program and provide brief descriptions of the principal elements of a WM audit.

The Role of the WM Audit in a WM Program

The primary objective of a waste minimization program is to reduce the quantity and/or toxicity of waste effluents leaving the production process. The essential elements of a WM program include the initiation and planning of the program, the planning and execution of a WM audit, and the implementation of the recommended measures that emerge from the audit process.

During the program initiation phase, the commitment of top management to reduce waste generation must be established, which results in the development of an organizational structure for the WM program and in the setting of waste reduction goals for the entire organization. The next step involves characterization of waste generation rates and waste characteristics. The program planning step follows, with the selection of the audit team(s) to carry out the actual auditing phase. The auditing process constitutes the most important element of the overall WM program, since it provides the key inputs for the generation of WM options, as well as for the decisions of which waste minimization measures should be implemented. Following the audit, selection of options for implementation are made based on feasibility analysis. Finally, WM measures go through the sequence of design, procurement, construction, startup, and performance monitoring.

Table 1. *Recommended Waste Minimization Audit Procedure*

Program Phase	*Activities*	*Product*
Pre-Audit	*1. Preparation for the audit*	• *needs list/inspection agenda*
	2. Pre-audit meeting and inspection	• *notes*
	3. Data compilation and waste stream selection	• *facility and process description*
		• *waste description*
		• *rationale for selection*
Audit	*4. Facility inspection*	• *notes*
	5. Generation of a comprehensive set of WM options	• *list of proposed options with written rationale*
	6. Options evaluation	• *independent options ratings by audit team and by plant personnel followed by joint review*
	7. Selection of options for feasibility analyses	• *list of selected options*
		• *options interim report*
Post-Audit	*8. Technical and economic feasibility analysis*	• *study or budget grade estimates of capital and operating costs; profitability analysis*
	9. Final report preparation	• *final report with recommendations*

Waste Minimization Audit Procedure

The execution of a waste minimization audit can be divided into three distinct phases, as shown in Table 1. The overall objective of the pre-audit phase is to gather and analyze the information necessary to select a waste stream(s) for the facility audit. The audit phase follows, the objective of which is to develop a comprehensive set of WM options and to screen them. The product of the audit phase is a list of options selected for further evaluation. A technical and economic feasibility analysis is performed for each selected option during the post-audit phase of the program. This phase ends with the preparation of a final report. The following paragraphs provide a brief description of each audit step.

1. Preparation for the audit

The objective of this step is to gain background information about the facility to be audited. Preparation should include examination of information sources related to the processes, operations, and waste management practices at the facility. The result of proper preparation should be a well-defined needs list, inspection agenda, or a checklist detailing what is to be accomplished, what questions or issues need to be resolved, and what information needs to be gathered. The needs list should be provided to the facility before the actual site visit to allow the facility personnel to assemble the materials needed by the audit team in advance.

2. Pre-audit meeting

The next step is a pre-audit meeting with plant personnel. This initial contact should include solicitation of plant personnels' views on the focus and function of the audit. The information needs identified in the previous step should be discussed. A tour of the facility should be performed to familiarize the audit team with the operations performed. During this meeting, it is important to establish a key facility contact.

3. Data compilation and waste stream selection

Selecting the principal waste streams or waste producing operations for the audit provides the audit team with the focus for the effort. The criteria used for waste stream selection include waste composition, quantities, degree of hazard, method and cost of disposal, perceived potential for minimization, and compliance status.

After all pertinent data are collected, they should be assembled in the form of a written facility description. The description should include facility location and size, description of pertinent operations or processes, and a description of the waste streams centering on sources, generation rates, and current methods of management. The report should include a written justification for selection of a waste stream(s) for study.

4. Audit inspection

The audit inspection is the ultimate step in the information gathering process. The governing objective of this step is to evolve a fuller understanding of primary and secondary causes of waste generation for the selected waste streams, and to cover the items missed in the pre-audit phase. The audit inspection must result in a clear understanding of waste generation causes. Useful guidelines for this step include having a detailed inspection agenda ready in advance, scheduling the inspection to coincide with the particular operation that is of interest, obtaining permission to interview plant personnel directly, obtaining permission to photograph the facility, observing the "housekeeping" aspects of operation, and assessing the level of coordination of environmental activities between various departments.

5. Generation of WM options

The objective of this step is to generate a comprehensive set of WM options. It is important at this point to list as large a number of options as possible, including WM measures currently in place in the audited facility. Option generation should follow a hierarchy to reflect the environmental desirability of source reduction over recycling, and of recycling over treatment. Options can be generated by examining the technical literature, through discussion with manufacturers of equipment or suppliers of process input materials, and through the use of a checklist. Table 2 provides a checklist suitable for solvent wastes.

6. Options evaluation

Each of the options postulated in the preceding step must undergo a preliminary qualitative evaluation. The objective of this evaluation is to weed out the measures that do not merit additional consideration and to rank the remaining measures in the order of their overall desirability. The evaluation should consider aspects such as waste reduction effectiveness, extent of current use in the facility, industrial precedent, technical soundness, cost, effect on product quality, effect on plant operations, implementation period, and implementation resources availability. It is recommended that the evaluation process be performed independently by both the audit team and the host facility personnel. A rating system has been developed to rank the measures in a consistent pattern and to provide a framework for resolving the differences in opinions.

7. Selection of options for feasibility analysis

Following the evaluation process by the two independent groups, the two sets of ratings are compared and discussed in a joint meeting in order to develop ratings which are mutually acceptable. The product of this meeting is a WM options list with revised ratings. The final ratings are then used as a basis for the selection of options for additional feasibility analysis. The number of measures promoted to the feasibility evaluation stage depends on the time, budget, and resources available for such study.

8. Analysis of technical and economic feasibility

The specific WM options selected for additional evaluation must be analyzed. Study-grade (e.g., ±30% accuracy) estimates for the capital and operating costs can be obtained from preliminary vendor information or factored estimation techniques. Once the costs are obtained, the analysis is focused on an estimation of profitability, based on conventional methods (payback period, internal rate of return, or net present value).

9. Final report preparation

As the concluding step of a WM audit, a final report should be prepared to summarize all the pertinent data, results, and recommendations.

Results of Waste Minimization Audits for Solvent Wastes

Waste minimization audits were conducted at two facilities generating solvent-bearing wastes. The following is a summary of the reports prepared for each facility.

Facility S-1A/B

Facility S-1A/B, located in Southern California, is a major aviation, industrial, and seaport complex supporting anti-

Table 2. *Source Reduction Options Checklist for Solvent Wastes*

General Options	*Comments*
Alternate cleaning agents	— *Possible replacements include steam and alkaline cleaners.*
Alternate paint stripping agents	— *Possible replacements include caustic, cryogenics, abrasives, and thermal paint stripping methods.*
Equipment cleaning	— *Uncontrolled use of solvent for cleaning can be a major waste generator.*
Dedication	— *Reduces the need for equipment cleaning between batches of product.*
Quality control	— *Reduces the generation of off-spec batches. Equipment that produces off-spec material must be cleaned before it can be reused.*
Mechanical cleaning	— *Use of wipers to remove deposits from tank walls can reduce the need for cleaning with solvent. Pipelines can be "pigged" before flushing.*
Inert blanketing	— *Prevents the drying of materials inside the equipment.*
Equipment modification	— *Can reduce the need for cleaning or reduce the waste volumes produced.*
Bag filters	— *Retain less material than cartridge filters. Can be cleaned and reused.*
Metal mesh filters	— *Can be back-washed during system flush thereby generating no filter waste.*
Clean-in-place systems	— *Often designed to recycle cleaning agent. High pressure spray systems often eliminate the need for using solvents to remove heavy deposits.*
Waste handling	— *Proper handling is crucial to the success of recycling solvent waste.*
Segregation	— *Increases the likelihood that a solvent waste can be successfully recycled.*
Standardization	— *Increases the amount of recyclable waste thereby improving the economics.*
Reuse	— *Dirty solvent can often be reused in less critical cleaning operations or be used as part of the product formulation.*
Recycling	— *Requires the use of a continuous or batch still.*
Heat Recovery	— *Many solvents can be used as fuel in industrial boilers/furnaces.*

Options for Cold Cleaning Tanks	
Tank location	— *Tanks near heat sources or drafts can exhibit large evaporative losses.*
Tank lids	— *Frequent use reduces evaporative losses.*
Removable	— *Seldom used if heavy.*
Hinged	— *Often used. Piston effect can cause emissions.*
Roll type	— *Best. Disturbs vapor zone least.*
Water seal	— *Used with chlorinated solvent. Water quality should be routinely monitored.*
Tank vents	— *Excessive use increases emissions. Flow rate should be less than 50 cfm/ft².*
Parts handling	— *Proper handling can extend solvent life and reduce losses.*
Precleaning inspection	— *Parts should be relatively dry. Excessive water can lead to acid formation when chlorinated solvents are used.*
Entrance/exit speed	— *Avoid speeds greater than 11 feet per minute to avoid drag-out of vapor.*
Part drainage	— *Parts should be properly racked so that solvent drains freely.*
Rack maintenance	— *Cracks can drag-out solvent and corrosion can contaminate the solvent.*
Cleaning efficiency	— *The greater the efficiency, the more parts cleaned per volume of solvent.*
Degree of agitation	— *Can be increased by installing a pump/jet, a mixer, or an ultrasonic unit.*
Two-step counter-current sequence	— *Allows a higher degree of spent solvent contamination to be reached.*
Emulsifiers	— *Provides additional cleaning action by dissolving grease and soil.*
Vapor degreaser	— *Can clean at much higher contamination levels than can cold cleaning tanks and provides a much better cleaning action.*
Options for Vapor Degreasers	
Operation	
Heat input	— *If too high, will increase solvent loss to the atmosphere.*
Cooling water temperature	— *Solvent vapor will not be recovered if too high and undue condensation of moisture from the atmosphere will occur if too low.*
Parts spraying	— *Spraying parts above the vapor line bypasses the emission control equipment.*
Overloading	— *Overloading collaspes the vapor zone which causes air to be drawn into the unit. Solvent loss occurs as the zone reforms and the air is expelled.*
Maintenance	
Leaks	— *Cooling coil/steam leaks can introduce excessive water into the unit.*
Water separator	— *Failure to routinely purge (remove water) can lead to acid formation.*
Stabilizer level	— *Stabilizers are added to chlorinated solvent to prevent acid formation.*
Cross-contamination	— *Trace amounts of different solvents can lead to acid formation.*
Sludge removal	— *Routine removal reduces the amount of solvent absorbed by the sludge and the potential for acid formation.*
Solvent recovery	— *Vapor degreasers can be operated as a still to recover solvent.*
Modification	
Freeboard height	— *Increased height can reduce solvent vapor loss due to turbulence/drafts.*
Freeboard chillers	— *Can be used to create a blanket of cold air which suppresses vapor loss.*
Silhouette entries	— *Reduce the open area of the unit thereby reducing vapor loss.*

submarine aircraft, helicopters, and aircraft carriers of the Pacific Fleet. Facility S-1A operations are mostly performed by military personnel, while facility S-1B operations are performed by civilians.

There are over 100 solvent end use points in the entire base. Solvent is used in many servicing operations, especially parts degreasing and paint stripping. Due to the magnitude and diverse nature of the operations performed, four stations were selected from the ten initially audited for a detailed analysis. The stations selected were Station #1 - Cold Cleaning Tank, Station #4 - Ball Bearing Cleaning, Station #6 - Vapor Degreasing, and Station #7 - Epoxy Paint Stripping. These stations represent a fair cross-section of the types of activities that occur at the base.

For the four stations selected, a total of 36 source reduction options were considered. Several of these options were then selected for further investigation, based on their high future reduction index. Additional information was obtained from further searches of the available literature and from contact with equipment vendors. The measures evaluated in detail included: use of a closed tank and increasing the cleaning efficiency of Station #1 by increasing the degree of agitation; increasing the cleaning efficiency of Station #4 by employing a two-step counter-current cleaning sequence; reclaiming solvent from spent 1,1,1-TCE at Station #6 by using the degreaser as a still; and continuous filtering of stripper solution at Station #7 (see Table 3). Measures that involved changes in operating procedures only were not considered for additional analysis.

Table 3. *Summary of Source Control Options Investigated for Facility S-1*

Station	Control Method	Waste Reduction (%)(c)	Waste Reduction (gal/yr)	Capital Cost	Savings	Payback
1	Closed Tank (d)	—	—	—	—	—
1	Increased Agitation	75(37)	495	$2,910	$ 360 620 (a)	8.1 Years
4	Counter-Current Cleaning	50(33)	300	$ 600	$ 220 380 (a)	2.7 Years 1.6 Years
6	Level Alarm	62(40-50)	246	$ 600	$ 980 (b)	7 Months
7	Sludge Removal	50(64)	364	$6,820	$2,770	3.0 Years

(a) Assumes no credit for the waste solvent.
(b) Excludes savings due to reduced disposal costs.
(c) Quantity in parentheses represents percent reduction in virgin solvent use.
(d) Modification of the existing tank would not be viable.

Facility S-2

Facility S-2, located in Southern California, is a major manufacturer of multilayer ceramic capacitors used primarily by the telecommunications and military electronics industries. Production operations are performed in two separate buildings located within close proximity to each other. Ceramic materials are formulated in the Annex Building and then transferred to the Main Facility where the capacitors are formed. Various finishing operations are performed at both buildings.

The major solvent waste generating operations audited at the facility include: cleaning of ball mills, slurry transfer pots, and slurry application systems with RM-513 (a proprietary solvent) and recycled 1,1,1-Trichloroethane (TCA); general cleaning with isopropyl alcohol (IPA) and recycled TCA; and the on-site recovery of spent TCA (see Table 4).

A total of 22 options were initially postulated for the reduction of solvent-bearing waste from the audited operations. Following discussions with facility personnel, seven of the options were selected for further investigation based on their high future reduction index. Additional information was obtained from further searches of the available literature and from contact with equipment vendors. The options evaluated in further detail include segregate and recycle RM-513 based off-spec slurry, segregate, standardize, and recycle cleaning solvents, segregate and recycle RM-513 flushing solvent, convert application system filters to bag/wire mesh type, segregate and recycle isopropyl alcohol waste, and install secondary recovery system for TCA primary recovery waste.

Observations and Recommendations

The following observations and recommendations were made as the result of the pilot audits:

- For one of the two facilities audited, the availability of the required process documentation was not satisfactory. Experience with these and other sites indicated that the availability and quality of the information varies significantly. Much information is available, however, from outside sources such as vendors, chemical suppliers, and literature.

Table 4. *Summary of Solvent Waste Minimization Options Investigated for Facility S-2*

Waste Source	Minimization Option	Waste Reduction gallons/year	Waste Reduction percent	Net Annual Savings(f)	Capital Costs	Payback Years(g)
Ball Mills and Transfer Pots	Segregate and recycle RM-513 wastes.	720(a)	28.8	$6,040	$25,750	4.3
	Standardize solvent used and recycle.	2,150(a)	86.0	$19,130	$25,750	1.3
Slurry Application Systems	Segregate and recycle cleaning waste.	725(c)	96.7	$5,400	$25,750	4.8
	Use bag type filters.	—	90.0(d)	$1,260	$23,950	19.0
	Use metal mesh type filters.	—	100.0(e)	$6,660	$9,830	1.5
General Cleaning With Isopropyl Alcohol	Segregate and recycle cleaning waste.	2,350	50.0(d)	$11,650	$25,750	2.2
TCA Primary Recovery	Install a secondary recovery system.	2,015(b)	73.3	$7,100	$25,750	3.6
All Waste Sources Shown Above	Use a common batch still for above methods.	5,810	54.3	$30,190	$25,750	0.9

(a) Based on waste volumes before solidification.
(b) Based on the volume of waste shipped off-site for treatment.
(c) See notes (a) and (b) above.
(d) Assumed value.
(e) Filters would be backwashed with the flush solvent so that no additional solvent would be required for cleaning.
(f) Net annual savings is the difference between the actual savings due to reduced raw material and disposal costs and the operating and maintenance costs.
(g) Payback period equals the capital cost divided by the annual savings. The payback period does not account for depreciation.

- Pre-audit activities, particularly the pre-audit site visits, were found to be extremely important in facilitating the audit process. Cooperation by the plant staff was improved when the audit team spent more time getting to know the host facility staff and how their organization functioned.
- Participation in the options ratings process is much improved when the host facility personnel are required to independently develop ratings of each of the WM options under consideration.
- Good operating practices recommendations must be presented with their economic dimension stressed in order to retain the interest of the host facility personnel. Otherwise, they can be seen as trivial and trite.

This report was prepared by staff of Jacobs Engineering, Pasadena, CA 91101.
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The complete report, entitled "Waste Minimization Audit Report: Case Studies of Minimization of Solvent Waste from Parts Cleaning and from Electronic Capacitor Manufacturing Operations," (Order No. PB 87-227 013/AS; Cost: $18.95, subject to change) will be available only from:

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